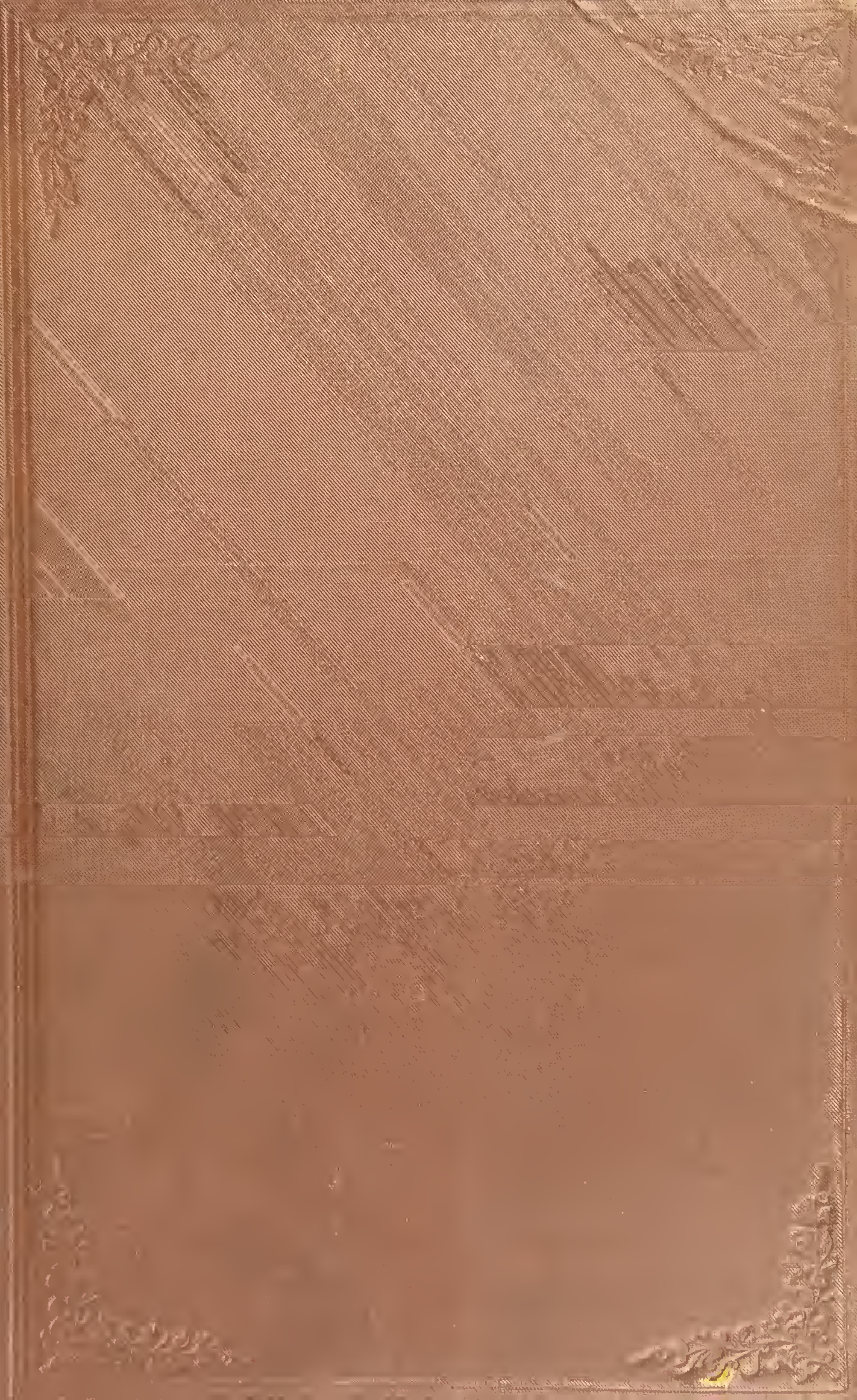

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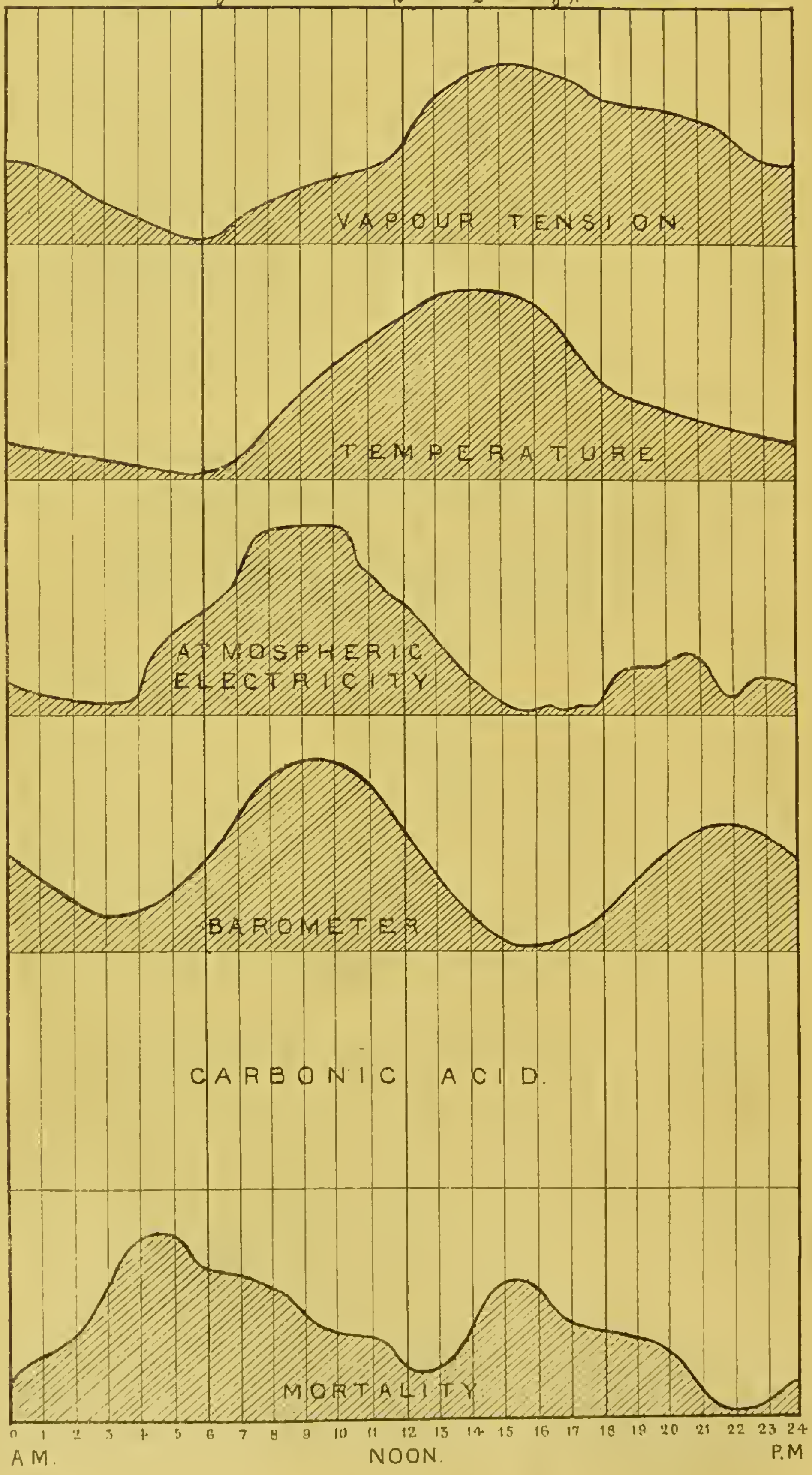
Plate 1.

CHART.

Shewing the correspondence between various Natural Phenomena and the hourly rate of Mortality during twenty four hours.



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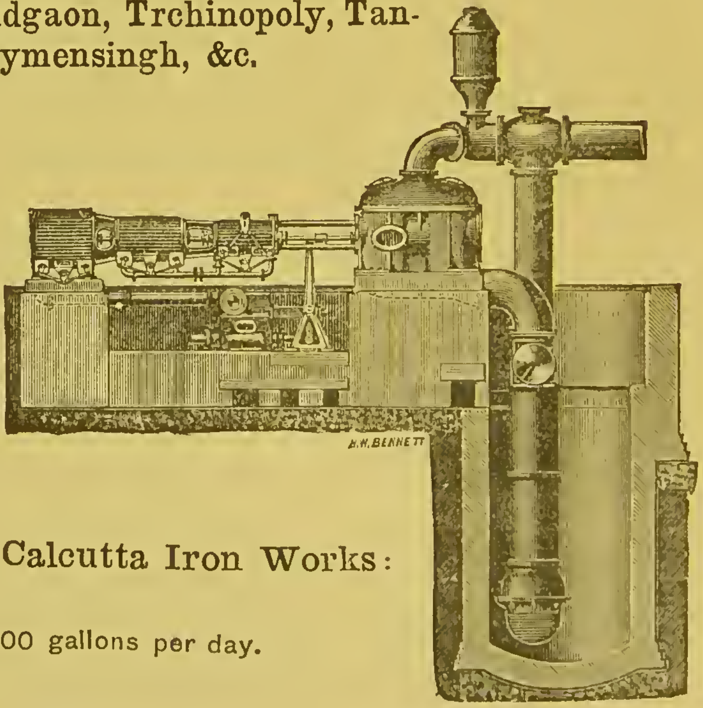

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PREFACE.

THE object of the present work is not to supersede, but to supplement, existing books on Sanitary Engineering, written in other countries, and used largely in India.

The literature of sanitary work in India exists, at present, for the greater part, in unpublished reports or scattered in articles among scientific and other journals. Public sanitary works are being actively pushed in many parts of the country, and it may be safely said that, at present, questions of public health have awakened more general interest than at any previous time.

Figures and instances, based upon experience in Great Britain, continue to be used either in advocating new works or in discussing those already established, while the radical differences existing between the climatic and other conditions of the two countries are often so great as to condemn a proposed work for India simply *because* it succeeded in England. Natural Law is the same throughout the world, but its manifestations have an infinite variety, and they only correspond under exactly similar circumstances, or in exactly similar countries.

The two great Hygienic Problems of water-supply and the disposal of waste material, around which all other sanitary works are grouped, are at present in a state of development which leaves much to be ascertained and to be done, that lies quite outside of all European experience. The rapidity of growth of organic matter, only equalled by the rapidity of its decay, introduces a time element into sanitary calculations in India, which is vastly different from the same factor in colder countries.

The value of a supply of good potable water has been established beyond all doubt in India by numerous works and by ample experience in mortuary returns, but the best economic limit of supply—for it is always possible to have too much—has not been settled. It is, on the contrary, rather complicated by the success that has attended the experiments in sewage irrigation at Madras, by which sewage has acquired a distinct commercial value. The discovery, for it is nothing less, that the whole of the liquid sewage of one of the largest Indian towns may be distributed immediately over cultivated land, not only without opposition from the Native cultivators and proprietors, but with their approval, opens a new prospect for urban sanitation.

The manurial value of excrementary matter is already sufficiently well known to afford a sound basis for our expectations regarding it, and when it is removed and distributed by water-carriage, the pumping power for unfiltered water will have to be adapted to give the sewage the best amount of dilution to suit agricultural purposes.

There can be no doubt that town sewage is destined to be applied to the land, but in the means of transport we have so far encountered enormous difficulties, traceable mainly to the rapid rate of decomposition of organic matter in a hot climate. We have neither succeeded in separating sedimentary matter from waste water before it enters the sewers, nor in making it flow out with the liquid before it has time to putrefy. The sanitary value of underground sewers has not yet been determined on their own account, and independent of the benefit of water-supply; and although sewage must be removed promptly from the neighbourhood of habitations, the best method of doing it does not appear to have been found. No Indian sewers remove their contents without producing much more smell than English sewers. Under the circumstances, they cannot be expected to do much better than at present; it remains, therefore, for us to find a remedy either in a modification or in a new type.

The low cost of labour and the comparative poverty of the people suggest a greater employment of manual labour in the maintenance of sanitary works than would be possible in England, and a greater economy in the cost of construction. The actual limit of each element can only be determined for any work on its own merits.

From a financial point of view, the utilisation of sewage and town-refuse cannot fail to gain increasing importance as its value for agricultural purposes increases and a new source of revenue for municipalities is developed. Sanitary work has hitherto been primarily based, and finally estimated upon the statistics of mortality of a town or district; and the mode of execution has too often been sought by the process of guess and trial. This is allowable in all work of research to obtain data, but it can only be condemned when applied, for example, to a whole sewerage system.

The design of works for sanitary purposes—if the labours of Dr. Augus Smith have any value—should be based on actual knowledge, not only of mortuary statistics, but of the condition of the air, and the subsoil water of the locality under consideration, in addition to that of the potable water.

At present we are destitute of both air and subsoil water analyses, but, it is to be hoped, that since a

Hygienic Laboratory has been established at the Madras Medical College, we shall not be long without those fundamental data so necessary to sanitary science. This Laboratory is admirably situated for its purpose: it will furnish data of the conditions accompanying the present high mortality prevailing in the City, for comparison with data to be obtained at some future time when sanitary works shall have brought the rate of mortality down to that of Bombay.

I have much pleasure in acknowledging the valuable assistance rendered me by Charles Chambers, Esq., F.R.S., in meteorological data on which this work so much depends, by Surgeon-Lieut.-Colonel T. S. Weir, Health Officer of Bombay, to whom I am indebted for statistical data, and by Dr. Thos. Blaney, Coroner of Bombay, whose long residence in the City, and whose intimate acquaintance with its municipal history and with the ways of its inhabitants, have been most willingly placed at my disposal.

I append a letter he has addressed to me, which resumes, in better words than mine, and with all the distinct character of a separate individuality, this greatest problem of our social life, which, for its successful solution, involves more collateral wisdom than any other subject

JOHN WALLACE, C.E.,
Bombay.

Grant Road, Bombay,
7th December, 1892.

DEAR MR. WALLACE,

This comes to thank you for confiding to me the fact that you have now ready for publication a work on Indian Sanitary Engineering brought up with the knowledge of the day.

No one that I know of has devoted his particular attention to Indian sanitary problems with a view of recording in a work of reference matured opinions and conclusions on the various sanitary wants of the people of this country. It is well known to sanitary experts, both Medical men and Engineers, that the climate of this country—including the rainfall,—the habits of the people, their poverty, and the religious apprehensions are widely different to what obtains in England, in Europe generally, in America and in Australia, and that the systems—say of sewerage, dry conservancy, house-building and ventilation, and even water-supply—which may be appropriate for the towns and cities of the countries I have named may not be equally appropriate for Indian towns and cities. If the diet, the social habits, the diseases, and the pecuniary condition of the Indian people are diverse from what obtains in England and in Europe generally, the sanitary works suited to the people of England and Europe generally may not be so well suited to the people of this country. Observers of sanitary progress in India have not failed to see blemishes and deficiencies in the sanitary works that have been laid down in various parts of the country. To give one illustration only. Poverty has not been an obstruction to sanitary work in Bombay. The City has expended more than eighty lakhs of rupees on its new system of sewers, to say nothing of the number of lakhs that were expended on various old systems, but after several years of practical experience, the City is now waiting the further advice of experts to remedy very serious existing defects of the system of street sewerage, where the sewers are impeded or obstructed by solid deposits. Worse still is it with the system of house drains and other house connections. Here, as in the street sewer system, the people have not understood the system, but by their ignorance and carelessness have destroyed it and made it more a curse than a blessing. In the fact that the Corporation are now carrying out six experiments in house connections in different parts of the town, in order to ascertain how the house connection system may be made to suit the people and the climate, we have a complete example that a system that works well in European towns works imperfectly or injuriously in India. European standard sanitary works, even the most modern ones and the newest editions, are not exactly suited for India, and no wonder, for they were not intended for India. They may be misleading, that I take it is your point.

As one who has devoted some attentions to Indian sanitation, it has afforded me pleasure to know that you have devoted your best energies to bring out a work on Indian Sanitary Engineering, which will be a useful guide to the muncipalities of this country that are preparing to introduce sanitary improvements. These municipalities must desire to move on safe lines and to commit no blunders, that is to say, to modify and to undo to-morrow what it has done to-day. I cannot even estimate in lakhs of rupees the money that has been wasted in Bombay in making improvements on the system of better experience. It is quite true that the whole civilized world is experimenting in sanitation. The best system is still imperfect. But what a lesson does this teach to Indian municipalities who have no funds to spare for gaining knowledge by "better experience." If we had a work on Indian Sanitary Engineering which embraced all the knowledge collected from many practical centres, and if to this was added well-known and well-digested scientific facts on subjects sanitary, which have hitherto escaped notice or inquiry, how valuable would such a work be? It would be a blessing to the millions who are disease-ridden, to the millions who are called upon to pay for sanitary works, to the municipalities who are responsible at once for municipal finance and municipal progress, and to the Government as the head of national public health.

I wish you success in your sanitary work, and hope I may live to hear it described as a standard sanitary volume in Indian Engineering.

Believe me to be,

Yours faithfully,

THOMAS BLANEY.

CHAPTER I.

Although Sanitary Works are governed by the same Natural Laws the world over, and although the refuse of towns has much the same constituents, with varying proportions, wherever the human race congregates, no one who had lived long in India and knew its people would think of providing them with the same sanitary appliances as are in vogue in Western Europe.

Climatic conditions of rainfall and temperature, atmospheric humidity and barometric pressure, the rapidity of organic decomposition, the force and frequency of the wind, the available materials of construction, and, last but not least, the habits and prejudices of the people, all require consideration upon their own merits, with a mind, fortified it may be, but still unprejudiced by European experience.

A very large proportion of the English works on sanitary matters are not only useless in India, but actually misleading—for the very care with which they have been prepared to meet the smallest details of local circumstance in England carries them far apart from the requirements of India.

In England, an assumption that the law will contribute to assist in enforcing the use and protection of such appliances as municipalities may decide to adopt, governs the design of many devices in common use, and permits the general introduction of more or less complicated apparatus. And the people, by reason of their education and their familiarity with mechanical devices, are able to benefit by many of the inventions of Sanitary Engineers, which could not otherwise be introduced among them.

In India, the case is just the reverse. Novelties of all kinds are looked upon with distrust and dislike; primitive custom is an unwritten law among the people. Common Law is to them no impartial and staunch friend, to whom they may appeal to protect their *rights* as subjects of the Sirkar. It is, on the contrary, an all-powerful Rajah, with a very uncertain temper, who must be flattered, cajoled, and, if possible, bribed, for his favour.

If the law were enforced in India against contraventions of the sanitary rules as applied in London, the prison accommodation and magistrate power would have to be increased tenfold.

With a climate having a mean temperature 30° above that of England, in which organic matter decomposes at a rate unknown in colder countries; with a people who take infinite pains to preserve themselves from defilement, and yet whose ideas of cleanliness are the reverse of those accepted in Europe: a people whose religious and social laws are one, and who are dangerously obstinate, if they even suspect that these religious rights are assailed, India offers a wide and most interesting field to the Sanitary Engineer.

The following description of a ceremony of purification, taken from the *Times of India*, is the author's own experience of the state of the Ganges at Cawnpore, on the 24th of May 1891. The occasion of the holiday was an eclipse of the moon which had taken place the previous night. The road to each bathing ghât on the Ganges was filled with a stream of Natives in their gayest dresses going to, or returning from, the bath, which is the first religious duty of the day. Many stayed for a few minutes in the small temple at the head of the broad flight of steps leading to the river, while others gave alms to the swarm of beggars, which forms such a prominent feature of an Indian holiday. The majority of the bathers were in one part of the river, opposite the Bhugwat Ghât, through which many of them had passed. There were about two hundred and fifty of all ages and of both sexes in the water together, bathing in the most decorous fashion, many of whom returned with their wet clothes upon them. Men, women, children, horses, and dogs were all in the water together, while on the banks were devotees engaged in prayer and in other religious offices.

Scarcely a hundred yards above the bathers, and at the edge of the stream, was a group of six large vultures and two long-legged scavenger birds. The vultures were pulling at an object which appeared above the water, while the other birds looked on. The object, on close examination, proved to be the body of a full-grown man, who had very probably died of cholera on the same morning, and had been hurried to the river without the ceremony of burning.

A hundred yards below the bathers was another fresh and unburnt body, stranded some three feet from the water's edge, with its attendant party of vultures, which were just beginning to feed. Half-way between the body and the bathers lay a partly burnt body that smelt horribly, having been in the water for some time.

It seems to be nobody's business to remove the drifting bodies from the neighbouring bathing-places; the vultures and the crocodiles are supposed to do all that is necessary. Bodies of persons who have died of snake-bite are also placed in the river without burning, owing to a belief that the Ganges water may possibly revive them.

Cholera is busy at Cawnpore at present, and as all the victims of this disease are put unburnt into the river, the people seem to be doing all they can for the spread of the disease. A single cholera body, dissected by vultures at the edge of a river and immediately above a large crowd of bathers, is likely to send cholera germs very freely among them. The bathers not only wash their mouths in the water, but drink, and, in many cases, carry it home for consumption. An analysis of water taken from among the bathers on this occasion might have revealed some surprising truths regarding the sacred river, or, more properly speaking, sewer, that runs by the most important towns of the North-West Provinces.

The question naturally arises: "What proportion of the mortality of the town of Cawnpore is due to defilement resulting from bathing in the Ganges?"

In India the sacerdotal character of a river does not resemble that of a priest in the matter of permanency. In a few years the Ganges will cease to be sacred and the Goomtee will assume the title with all its honour and ceremonies. It is satisfactory to think that what the Ganges loses in sanctity will be more than compensated by what it will gain in cleanliness, for as no advantage will accrue to the dead by being thrown into it, their number will be considerably diminished.

The means of the poorer classes of Hindus are much too small to pay the cost of completely burning their dead and reducing them to ashes, previous to consigning them to the river. If this could be done, the river would actually be the purer for it; but what happens in many cases is that the body is slightly grilled, and if not eaten immediately, it decomposes and pollutes and poisons the water. It is to be hoped that the duty of burning dead bodies will soon be taken over by municipalities in India and made a civic institution, so that the poorest classes may be as certain as the rich that their last religious rites may be completely and properly performed.

However the spirit of modern enlightenment may condemn the wholesale pollution of potable waters and their subsequent use for bathing and drinking, it is somewhat reassuring to know, that it all forms part of a great cultus for which the people submit to much incovenience and to which they make daily sacrifices.

Whatever the result may be, their sincerity cannot for a moment be doubted. The "force" is there, whether it be "in the wrong direction" or not.

Modern sanitation may be described as a method of giving practical effect to some of the objects which the Hindu has striven for ages to attain.

That the air he breathes, the water he drinks, and the food he eats should be free from all injurious admixture is the common object of Eastern faith and Western science, and it should form a bond of lasting interest between them.

If the Sanitary Engineer would succeed in his work, he must come to it well equipped. A hard constitution and a strong stomach are the first essentials. To this must be added such a workshop-training as will give him a thorough practical knowledge of the processes of construction in mechanical work. He must understand design in the sense of comprehending all the processes of manufacturing his devices, and their relative cost. He must have an intimate knowledge of the materials the country can supply for his needs, and the properties of those materials.

He will be called upon to carry out his works more cheaply and under greater difficulties than in Europe, and will frequently have to design new appliances for which no models exist, and in which work neither the mechanical engineer, nor he of roads, bridges or canals, can offer much assistance.

It goes without saying that he must know the theoretical science of his work, which includes a good deal of meteorology, hydraulics, building, and a certain amount of chemical knowledge, also a practical and theoretical acquaintance with ventilation, which must be acquired in the tropics, or, at least, corrected there. The Sanitary Engineer would need a temper well under control, and something of the art of getting on with people, for he will be looked upon with suspicion and distrust by most of the people who do not know him, that is to say, the majority of those with whom he has to deal.

If he is a sensible man, he will fix his standard of excellence considerably below perfection; he will neither try to do impossible things, nor expect to awaken much interest among the people for whom he works. Whatever he makes will be subjected to the roughest usage, and will suffer every kind of abuse. Simplicity is absolutely essential even at the cost of some degree of efficiency. The Native of India does not cultivate the sense of smell like the Native of Europe. On account of his insanitary surroundings, the Indian has for ages past lost that perception of smells, which distinguishes the European and renders him something of a faddist in the eyes of his Indian fellow-subjects. Even in the matter of perfumes, it is only the strongest that appeal to the popular taste. The Indian, therefore, will not and cannot recognize nuisances as we do. It is useless to expect it of him.

Some palpable benefit must accompany sanitary reforms, that is to say, a benefit that he can realize, in order that he may appreciate them. This is not easy to accomplish, for sanitary works generally take time to make their value felt.

The fact that the Native of India is constantly on the watch against possible defilement is in itself an admirable characteristic whether his ideas of defilement agree with Western definitions or not. He makes daily sacrifices to his convictions, and no one will doubt his sincerity. With better knowledge that education will bring him, he will learn that clean clothes and a clean skin, although excellent things in themselves, are not enough to compensate for the use of impure water, or the respiration of air contaminated by rotting sewage that lies around his dwelling.

He has only to add a knowledge of the impurities that kill physically to his faith in the defilement that degrades him réligiously in order to become the healthiest man in the world.

A careful study of his habits, beliefs, and prejudices will be of the greatest value to the Sanitary Engineer in India, for until he can think in parallel lines with the Native, he will never be able to interfere successfully with his daily mode of life.

It may be somewhat encouraging to the English Sanitary Engineer in India to remember that in his opposition, active or passive, to sanitation, the Indian is not a bit worse than the Englishman at home. The present generation knows little of the way in which sanitary observances had to be *policed* into the public. Even at the present day the number of convictions for neglect of regulations, or for positive nuisances in any large town, shews that with all the improvement in public health, which has taken place during the past fifty years, and which is clearly traceable to wise and necessary restrictions, the British people still require supervision, and, at times, coercion, to make them attend to their own best interests.

Notwithstanding the general advance of education and the great increase of the members of the medical profession in India, the attitude of landlords and of the public generally towards house sanitation is one of complete indifference. The fashion of making journeys for the sake of change of air, and for relaxation, is increasing with the facilities afforded by improved modes of transit by railway and steamer, and it seems that in many cases this system of recuperation is counted on to compensate for the neglect of almost every sanitary precaution in every-day life. No class is entirely free from this charge.

A system of life in which the vitality is reduced to 70, 60, or even 40 per cent. of its possible maximum may well be said to be a poor result of modern civilization, and a serious drawback even when accompanied by more than the average of worldly success. The real physical condition of our bodies, during the greater part of our lives, is neither that of robust and perfect health, nor that of absolute prostration from sickness. We rather fluctuate in a state of reduced vitality, only touching our fullest vigour at very rare interval, and more frequently approaching the borderland beyond which is sickness and death.

It is impossible to doubt that if the same attention were given to hygiene as to the subject of dress, a far better average result would be obtained in health than prevails at present. One-half of the money spent in journeys for the restoration of health that need never have been lost, would, if properly expended on house improvement, result in a far better average state of life and an increased capacity for every enjoyment.

This public indifference to sanitary matters has led in England to an experiment, the results of which are published in the Report of the *Lancet* Special Commission on Sanitation in relation to the Law and Practice of House-letting, published 20th August 1892. An invitation was sent by this newspaper to one thousand house agents and surveyors in different parts of the country to give their opinion on the following list of questions:—

I.—Whether the information usually supplied by clients to house agents respecting the sanitary history and condition of the property they are asked to let is sufficient.

II.—(*a*) The sort of information usually supplied;
(*b*) The kind of information which could and should be furnished.

III.—Whether the house agent was prepared to make or obtain an efficient survey of a house and its sanitary arrangements.

IV.—Whether Section 12 of the Housing of the Working Classes Act, which renders it necessary that tenements to be let shall be reasonably fit for human habitation, should be extended to all houses without distinction.

V.—Whether the opinions expressed on the above would apply to houses and lodgings let for short periods at sea-side places and health-resorts.

VI.—Whether there is anything not covered by the foregoing suggestions which should be considered.

The appeal met with a prompt and courteous response from those to whom it was addressed, and such a mass of information was placed at the disposal of the Commission, and so many valuable practical suggestions put forward, that they have not only been able to appreciate the causes of the present unsatisfactory state of affairs, but also to offer for discussion some methods by which pressing evils may be remedied.

The Report states that "the prevailing opinion among our correspondents appears very decidedly to be that the amount of information placed at their disposal by landlords for the benefit of proposing tenants is quite insufficient to enable them to give an accurate and trustworthy opinion of the house they are asked to let or sell. The majority regarded the silence of the landlords as due to ignorance, and not to the wilful suppression of defects, although some maintain that the question of sanitation is passed over on account of the ruinous expenditure which drainage alterations entail upon the landlord. In some towns, such as Leicester, Eastbourne, Brighton, and Hastings, where houses are efficiently inspected by the local authority, the fullest information is obtainable, and landlords have little to gain and much to loose by the concealment of sanitary defects. Some house agents inform us that they always advise the proposing tenant to have the opinion of an independent surveyor, while one or two admit that the bare mention of sanitary defects may cause the agent the loss of his client. On the other hand, it is a significant fact, when we are told that once a landlord has been compelled to put his drains in order and holds a certificate to that effect, he loses no opportunity of putting this forward as an additional attraction to his house.

"Many suggestions are made by the agents and surveyors as to the sort of information that should be furnished by landlord to tenant, regarding the drains and sanitary fitting of a house. All agree that a survey should be made before the house is taken, although some say the landlord should guarantee their condition, while others consider that the tenant should verify them at his own cost. Others, again, maintain that the house agent who often does make the survey is not a proper person on account of his position between the contracting parties.

"It is stated that in Blackpool every tenant can procure a survey of his drains by application to the Medical Officer of Health.

"Nearly all agree that the condition of houses and lodgings let for short periods at health-resorts is urgently in need of reform. Many of these houses, instead of being health-resorts, are veritable death-traps, and liable to become centres of infection. Many agents have suggested that hotels, lodgings, and boarding-houses should be under the control of the local authority, by whom they should be licensed, periodically examined, and certificated. It appears that the sanitary authorities of many health-resorts have already become aware of their responsibilities, and are taking active measures to ensure the safety of the public.

"At Eastbourne the Corporation issues a sanitary certificate on conditions which rest with this department to decide. A very great improvement has been effected during the last two years in all classes of property, and the certificate being regarded by visitors as a safeguard, the number of houses fulfilling the stringent conditions of the same is daily increasing.

"In an able summary, the *Lancet* comes to the conclusion that there is a vast amount of ignorance abroad, both amongst landlords and tenants, as to what sanitary conditions should be fulfilled before a house may be considered habitable, and that sanitary defects are largely prevalent in houses in all parts of the country, especially in those erected before the adoption of the Local Improvement Acts or Model Bye-Laws, and that some reform is necessary in the law and practice of house-letting for the better protection of tenants, and, we think, in the end, for the advantage of landlord also.

"To attain this desirable result, however, some plan must be evolved, which, while affording effectual protection to the tenant, will not inflict a positive injustice on the landlord. Some of our correspondents have urged that the matter is entirely in the hands of the tenant, and that, as it is the duty of every man to look after himself, no further legislation is desirable. It is contended by them that all a proposing tenant has to do is to call in his own surveyor and be satisfied by an expert opinion that the drainage is in good order.

"We must confess that we cannot see why a landlord who spares no trouble to put the rest of his house in order should systematically overlook the condition of the drains, or pass them over with the statement that they are 'all right' or have 'given no trouble.'

"Nor are we able to appreciate the logic of the rule which says that the tenant must pay for the privilege of pointing out to the landlord that he is letting a house with the drains out of repair.

"Now, the plan which appeals to us most strongly, and one which appears most likely to secure the desired end most easily and smoothly, is that which has already been put in action with successful result at Eastbourne. By this method the local authority offers to grant certificates to landlords, if the houses come up to their standard of excellence, and houses so certificated are put upon the register of the local authority.

"The sanitary authority has acted most wisely by making the registration a voluntary one, for, by so doing, they have converted what might have been looked upon as a grievous hardship into a mark of distinction.

"As was to be anticipated, landlords have not been slow to avail themselves of the privilege, for it necessarily affords them a better chance of letting their houses, and we have little doubt that in time the majoirity of houses will have been put on the register.

"While we would advocate the system of voluntary registration for private houses, we think that in the case of hotels, lodging and boarding houses, registration should be compulsory. Our remarks would apply with especial force to sea-side places and health-resorts, whither people go in search of health and find perchance, instead, a sick-bed, or something worse.

"In houses of this class the public have not the opportunity, however capable they may be, of satisfying themselves about sanitary conditions, and it is only fair that they should be protected to the fullest extent.

"Once having gained a certificate from the local authority, how long shall it be considered to hold good? We would suggest that in the case of hotels, lodging and boarding houses, the renewal should be annual, the fresh certificate being granted, provided no nuisance has arisen in the interim. Private houses, we think, might be certified at each change of tenancy, notice being sent to the local authority when this occurs, or, in the case of long tenancies, at intervals of not more than seven years' duration.''

This Report is characterized throughout by that thoroughness that has long been a feature in the *Lancet*, and although its recommendations cannot all be adopted in India, it is a most valuable contribution to applied sanitary science, exposing the work, and the object of the work, in the same clear light together. House agents in India are not surveyors, and a large proportion of the landlords would rather pay the Sanitary Inspector to let their property alone than invite inspection with a view to sanitary improvements. Tenants rarely interest themselves in the sanitary fittings of their houses, and a tenement must have acquired a very evil name before people begin to avoid it.

A voluntary system of registration, such as has succeeded so well at Eastbourne, is not likely for a long time to become popular in India: the people must first be educated to appreciate it.

At the same time it should always be possible, in any well-regulated municipality, for a citizen to obtain information, positive or negative, regarding a house which he proposes to take, and concerning which he has no other means of information. Thus, a house that had been the subject of frequent complaints on account of nuisances which had not been abated, or which had been only partially abated, might be avoided by people who wished to preserve their health; and whose claim on the protection of the town authorities against an unscrupulous or indifferent landlord is perfectly legitimate.

Such a report furnished by the Health Department should, of course, be paid for by a fee that would cover the cost, and which would prevent any needless abuse of the privilege.

CHAPTER II.

Meteorology.

In order to appreciate in the best degree the conditions under which sanitary work must be carried out in India, the climatic peculiarities will be, as much as possible, considered in comparison with those of England.

Once these conditions are fully understood, the engineer will be able to decide, with safety and certainty in most cases, whether he may accept and adopt imported devices, or whether he must strike out a new line for himself.

The composition of the air varies very little when not contaminated by local impurities. The following is the composition of average atmospheric air :—

Oxygen	209·6	per 1,000 volumes.
Nitrogen	790·0	,, ,,
Carbon dioxide ...	0·4	,, ,,

It is never absolutely pure, and it contains organic dead or living matter, inorganic matter, ammonia, ozone, &c.

The carbon dioxide varies most, and the nitrogen least, of the three prime constituents. Impurities, particularly of the organic class, diminish rapidly with distance from the earth.

Mr. Tichborne published in 1870 some analyses of the dust of the streets in Dublin. In the street the dust in the air contained 45·2 per cent. of organic matter, chiefly stable manure finely divided. At a height of 134 feet from the surface the quantity was reduced to 29·7 per cent.

Dry air will carry much more of solid impurities than damp air, as the weight of the impurities is much increased by moisture. A curious point in this subject is noted by Angus Smith, who says that although rain be continued for days, organic matter is never entirely absent from the air. It has often been observed in India that mosquitoes and flies are only found at a moderate distance from the ground. They may swarm in jungles from 500 to 1,000 feet above the sea, but in buildings of 60 feet and upwards they begin to disappear. The author has observed, when sleeping at night on the gallery of the old Portuguese Lighthouse at Colaba, Bombay, that at an elevation of 85 feet from the ground no flies of any kind were to be seen. There is probably no food for them at that height. In the bungalow at the foot of the Lighthouse mosquitoes and other flies were numerous at the time of observation. The same thing is observable in all the lofty public buildings of the City, and, in addition, the increased purity of the air is evident to the most ordinary observer.

Gaseous impurities rise much higher than solid particles.

Fedor of Buda-Pesth in 1881 stated that the proportion of carbon dioxide is always greater at the ground level than at one metre above it. According to Parkes, the amount in normal air is from 2 to 5 volumes in 10,000; it increases slightly up to 11,000 feet of elevation, and then decreases.

Rain is the great purifier of the atmosphere. All the gases of combustion, putrefaction, and respiration, not directly absorbed by plants or by the earth, are met and absorbed by rain or vapour and brought to the ground, to do their work in Nature's great laboratory.

Temperature.

The temperature of the air and the water in India, on account of their influence on waste organic matter, deserves our full consideration.

The following figures representing mean annual temperature of the air in various parts of the world will shew the position of India in this respect :—

TABLE I.

London	49·2° Fah.
Edinburgh	47·5° ,,
Paris	51·4° ,,
Cape of Good Hope	66·4° ,,
Hobart Town	52·3° ,,
Copenhagen	46·8° ,,
Moscow	38·5° ,,
Vienna	50·2° ,,
Constantinople	57·4° ,,
Lisbon	61·5° ,,
Cairo	72·3° ,,
Kandy	72·9° ,,
Calcutta	78·4° ,,
Bombay	79·13° ,,

Thus, between London and Bombay there exists a difference of mean temperature equal to 29·2° F., and in the case of Edinburgh the difference is 30·9° or nearly 31° Fah.

The range of temperature at the following places is shewn below in monthly mean readings :—

TABLE II.

	Max.	Min.	Range.
London	87·7°	18·4°	69·3°
Lucknow	114·3°	41·0°	73·3°
Allahabad	116·5°	40·8°	75·7°
Bombay	100·2°	53·3°	46·9°

It is thus evident that sanitary works in India must carry out their purpose under circumstances much more difficult than those prevailing in England.

At a temperature of 55° F., and under, putrefaction is greatly retarded; it increases steadily with increase of temperature up to 140°, at which point albumen coagulates, and direct oxidation is supposed to begin.

An increase of 30° F. in the temperature of the air reduces its specific gravity by 4·308 per cent., the pressure being constant. Similarly, a cubic foot of water which at 52° weighs 62·377 lbs. will weigh only 62·15 lbs. at a temperature of 82° or ·36 per cent. less. Their momentum, when in movement, and their inertia, when at rest, are different as compared with air and water at lower temperatures.

Yachtsmen in Bombay Harbour have observed that their racing sails must be larger in India than at home to get the same speed out of their vessels with a wind of a given velocity, and sanitary engineers have had occasion to note that a greater velocity of current is required in Indian than in English sewers to move their contents towards the outfall. The hydrostatic pressure of water is also affected by its temperature. If the pressure per square foot due to a depth of 100 feet is 6237·7 lbs. at 52°, it will be reduced to 6215·0 lbs. at 82° F. A column of water 100 feet high at 52° would be equivalent in weight to another column at 82° with a height of 100·36 feet.

Sewage matter, including night-soil, is estimated to take from three to four days to putrefy in England. In India organic matter in sewage begins to decompose within one hour of being discharged into an underground sewer, owing to the ferment with which the sides of the sewers are coated, and also to the high temperature prevailing in the sewer. Excrementary matter, solid and liquid, are discharged from the body at a temperature of about 98° F. in all countries, but in England they may pass at once into sewers, where the temperature is generally below 55°, involving an immediate cooling of at least 43°, by which putrefaction is retarded. In Bombay the same matter passes into sewers having a temperature of not less than 75·2°, causing only half the reduction of temperature that takes place in London, and leaving heat enough to assist the active putrefaction that will very shortly be set up by contact with other decomposing materials.

Putrefaction varies in activity at any given temperature with the amount of water-vapour in the air. The deterioration of meat during hot and damp weather, as compared with hot and dry weather, is a familiar example. Refuse, therefore, that is wet, but not lying in water, will desiccate in a hot dry wind, while it would not in the warm moist air of Bombay or Calcutta.

The slow action of dry air, even when hot, upon organic substances, is observable in Upper Egypt, where, in the dry air and unvarying temperature of the catacombs, leather goods, wooden furniture, clothing, cordage, &c., last thousands of years. The same articles kept underground in Europe for a tenth of the time, and at a much lower temperature, would perish through the influence of water-vapour which increases the activity of decomposition.

The influence of the sun, to which we may trace all the heat on the surface of the globe, and all natural currents of air, is a potent factor for good and evil in all sanitary problems. If left to act upon the ground around a house littered with solid refuse of all kinds, and sodden with liquid filth, it will breed disease and cause death to the inhabitants.

Acting on a reasonably clean surface of ground or of street, it purifies it, and its action on the ground and on the surface of buildings is to set up, by convection, those vertical currents of air, which, in a country of frequent and prolonged calms, are of inestimable value, providing as they do a natural system of ventilation. Hence the great sanitary advantage of providing wide streets, upon which the sun's rays may have the freest possible play during a portion of the day, and of limiting the height of houses in all narrow streets. In a neighbourhood of narrow streets, where the eaves of the houses almost overlap each other, the direct absorption of the sun's rays is taken by the roofs, and the circulation of air, due to convection during the day, and more actively towards evening (when the difference of temperature between the air and buildings is greatest), takes place from the roofs upwards, and not from the ground, as it should.

Exposure to the influence of the sun is equally necessary to all the higher examples of animal and plant life. Other things being equal, the human beings who are most in the sun are healthier and live longer than those of the same race who are rarely exposed to it.

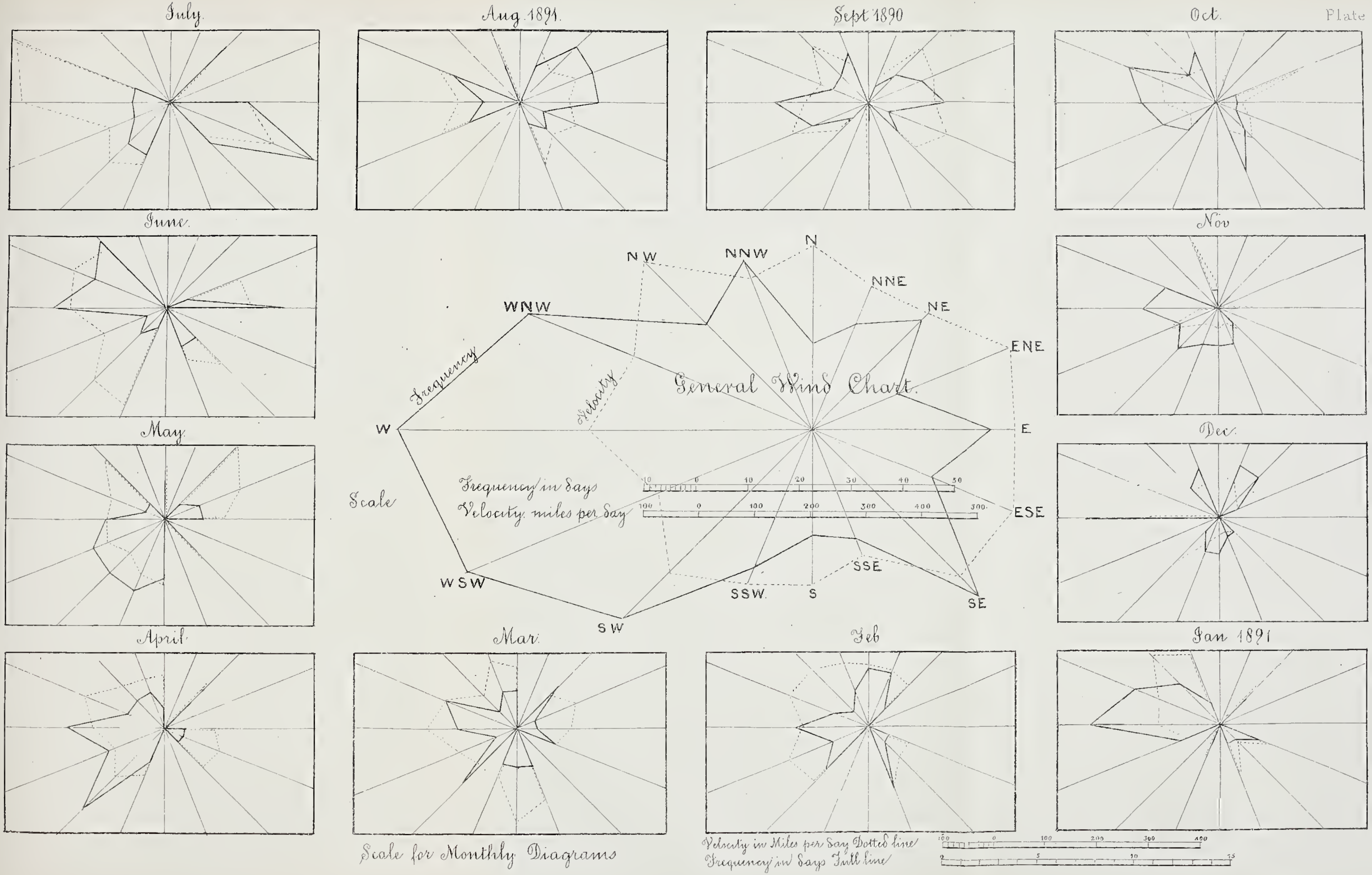
Shade temperature is a term which, when applied to an inhabited building, has a very variable meaning. It has no fixed relation to the temperature of an object directly exposed to the sun's rays, but is greatly influenced by radiation from surrounding objects already heated by the sun, and, again, modified by any currents of air that may pass through the place. The temperature of a closed room on the south side of a house is higher than that of a closed room on the north side, not because the wind is hotter on one side than the other, but because one side of the building absorbs more heat than the other, and radiates part of it into the building. The amount of heat absorbed depends principally on the colour of the external surface. If the walls of the building were removed, leaving only the roof in place, the shade temperature would be equal throughout the shaded part. Observations made in balloons prove that the influence of the sun's rays in heating the air they traverse on their way to the earth's surface must be exceedingly small, and that, consequently, the heat acquired by the air is received at second-hand by contact with the surface of the earth or with objects upon it. The heat of the air passing over dark-coloured ground or black rocks is greater than that of air passing over yellow sand.

The period of exposure of the land to the sun's rays has a great influence on the temperature of the air. In England several weeks of clear skies in midsummer will heat the earth until the climate becomes tropical, and plants and animals begin to die. In India, during the monsoon, a continuance of cloudy weather, with or without rain, brings about a considerable reduction of the temperature of the earth's surface. The application of these facts will be found in the Chapter on ventilation of dwellings.

Winds.

The velocity and frequency of the wind in India are, generally speaking, not sufficient to warrant the use of windmills. It is a land of gentle breezes and prolonged calms, varied by occasional, but rare storms of wind.

Plate II.


July.
Aug. 1891.
Sept 1890
Oct.
June.
Nov.
May.
Dec.
April.
Mar.
Feb
Jan 1891
General Wind Chart.
N
NNE
NE
ENE
E
ESE
SE
SSE
S
SSW.
SW
WSW
W
WNW
NW
NNW
Frequency
Velocity
Scale
Frequency in days
Velocity miles per day
10 0 10 20 30 40 50
100 0 100 200 300 400 500
Scale for Monthly Diagrams
Velocity in Miles per Day Dotted line
Frequency in Days Full line
100 0 100 200 300 400
0 5 10 15

The slow horizontal movement of the air is one of the principal reasons for the intensity of the smells, as it receives a greater saturation of impurities in passing over a foul spot. This is aggravated by the narrow streets and crooked alleys that are common in all towns, built without either municipal or Imperial supervision.

There are acres of such places in the large towns where the wind rarely penetrates, and where convection produced by the change from day to night temperature performs most of the ventilation. With a slow moving wind it becomes a matter of great importance that factories carrying on offensive trades, slaughter-houses, and depôts of night-soil or organic rubbish should not be established too near a town or in the line (to windward) of the prevailing winds, as the air charged with offensive odours passes slowly through the town, causing the greatest possible amount of annoyance or injury to the inhabitants. By a careful observation of the force and direction of the wind, the influence of unwholesome processes or manufactures may at times be traced to some distance from their source.

In Plate II. will be found a series of Wind Charts illustrating the force, frequency, and direction of the winds at Cawnpore between October 1889 and July 1891. The central diagram gives the results of the whole period, while the twelve diagrams arranged round it shew the same indication, month by month, from September 1890 to August 1891, inclusive. For purposes of observation on the relations between the ventilation of a town and the public health, the monthly diagram is much more useful than the annual one, as it permits the effect of the winds to be associated with other phenomena.

These diagrams were made up from data obtained from the Observatory at the Goverment Telegraph Office, Cawnpore. Observations were made in sixteen directions indicated in the central diagram. The number of days in the period represented by any diagram, during which the wind blew from any point, is represented by a full line, and its velocity per day of 24 hours is shewn by a dotted line. Distances are all measured from the centre to the full or the dotted line. Thus, referring to the central diagram, West-winds blew for 80 days, according to the scale measurement, during the period represented by the diagram, and the *mean* velocity was 59 miles in 24 hours, or rather less than 2·5 miles an hour. By reference to the monthly diagrams, the velocity ranges from 40 to 325 miles in 24 hours. If the extreme range is wanted, the original records have to be referred to. It was observed, by reference to the map of the town, that in the month of June 1891, when cholera was unusually active in the Civil Lines among Europeans, the affected locality was for about one-third of the month in the lee of a collection of very foul night-soil trenches, the wind blowing at an average rate of 7·2 miles an hour. Night-soil had been deposited in pits, 20 feet square and 4 feet deep, without any covering, and the ground being almost pure clay, the stenches during the putrefaction and drying of night-soil to poudrette were most offensive.

As cholera was much more active in certain parts of the City than in the Civil Lines, there is every reason to suppose that infected fæcal matter was thrown into the open trenches.

The influence of the wind upon the evaporation of water will be apparent from the following figures: the results of experiments made by Mr. T. Box :—

TABLE III.

Of Evaporation in Still Air.

Temp. of the Air and Water 82° F.	Humidity of the Air in per cent.							
	Dry.	30 °/₀	40 °/₀	50 °/₀	60 °/₀	70 °/₀	80 °/₀	90 °/₀
	Grains of Water evaporated per square foot per hour.							
	426	298	256	213	170	128	85	43

TABLE IV.

Of Evaporation in a current of Air, Evaporation in Still Air being unity.

Temp of Air. 52° to 57° F.	Calm Air.	Fresh Breeze.	Strong Wind.	Gale.
	1	4·4	8·8	12·4

Table III. shews that, with a constant temperature, the rate of evaporation depends on the humidity inversely, being greatest in dry air, and least when the air is already loaded with 90 per cent. of what it can carry of water-vapour, and Table IV. shews how, with a uniform humidity and a slightly varying or uniform temperature, the rate of evaporation is in direct proportion to the rate of movement of the air.

Rainfall.

The country possesses few rivers that are navigable all the year round, owing to the rainfall taking place only during a limited period of the year. The largest of them are, during the dry season, only navigable by small craft, and it is not yet known if the volume of the Ganges during the dry season will be capable of receiving and purifying the sewage of all the large towns on its course.

The amount of rainfall varies greatly in various parts of India :—

TABLE V.

Bombay (Colaba)	it is	72·25	(average).
Karachi	,,	7·34	,,
Hyderabad (Sind)	,,	8·00	,,
Nagpore	,,	45·09	,,
Allahabad	,,	38·51	,,

And it falls within four or five months in the year. The greater part of it runs to the sea.

The effects of the monsoon rains vary very much according to the manner in which they fall. In the dry season, the surface of the ground in towns is gradually fouled with the sullage and other refuse thrown upon it, and the greatest foulness is reached when the monsoon breaks. If the rain is copious and sustained for several days, the surface receives such a washing as to carry away most of the filth with which it has been charged, and an improvement in the public health follows. If, on the contrary, the rains are interrupted by periods of sunshine, the action of the distilled water on the sewage-soaked ground is to aggravate decomposition, and an increase of malarial diseases is the immediate result. The beginning of the monsoon, which washes the surface of the ground, carries many impurities into canals and rivers, rendering the water less wholesome than at other times. With the rains comes a greatly reduced period of sunshine and a corresponding fall of temperature. This is more remarkable in the interior than on the sea-board, where the temperature of the ocean controls that of the land. Beyond the reach of the sea breezes, the reduction of temperature following several days of cloud and rain is very considerable, and renders the change to heat and intense moisture, in the intervals when the sun appears more unpleasant and unwholesome than it would otherwise be.

The humidity of the atmosphere in a country with such a width from sea to sea, and with such long periods of dry weather, must necessarily vary a great deal.

There are places in Sind where it never rains at all, and where the relative humidity of the air is as low as 12 per cent., while at Colombo the average relative humidity is 79 per cent., and at Bombay 77 per cent.

As the capacity of the air to hold water-vapour in suspension varies with every degree of temperature, the significance of the term "Relative Humidity" will be best illustrated by the following table, shewing how much moisture a thousand cubic feet, or a cube of air 10 feet each way, will carry, at various temperatures, when saturated :—

TABLE VI.

Of Saturated Air.

Temperature of the Air.	Weight of Water-vapour 1,000 c. f. will carry.
32° Fah.	0·30 lbs.
42° ,,	0·44 ,,
52° ,,	0·62 ,,
62° ,,	0·89 ,,
72° ,,	1·25 ,,
82° ,,	1·72 ,,
92° ,,	2·36 ,,
102° ,,	3·20 ,,
112° ,,	4·33 ,,
122° ,,	5·84 ,,

Thus it is seen that at the freezing point (32° F.) air cannot carry more than $\frac{3}{10}$ of 1 lb. of water-vapour in one thousand cubic feet (at lower temperatures the quantity will be less), while at 122° F. the air, if saturated, will carry 5·84 lbs. of water-vapour in suspension. Such a state of temperature and saturation is only to be found in a vapour-bath.

The air is rarely completely saturated during the day-time, even during heavy rain. A fog will, however, bring the readings of the wet and dry bulb thermometers to equality, indicating complete saturation. Saturation most frequently takes place on damp nights during a falling temperature. As in cooling, the capacity of the air to hold water-vapour in suspension is reduced, the vapour, which only partially saturated it at sunset, becomes too great in quantity to be held in suspension at the lowered temperature, and water begins to be precipitated. This is the *dew-point*, and indicates complete saturation.

Relative Humidity is a term that has been adopted in Meteorology to indicate any proportion of the total quantity of water-vapour that the air would carry at a given temperature, therefore the expression " Relative Humidity" (or Saturation) 0·50. Temp. 82° means that air at 82 degrees had, at the time of observation, 50 per cent. of the water-vapour in suspension that would saturate it. By the last table it appears that at 82° air will carry 1·72 lbs. of water per 1,000 cubic feet, so 0·50 of Relative Humidity means the half of 1·72 lbs., or ·86 lbs. of water-vapour per 1,000 feet of air.

Dampness and dryness of the air are not to be expressed merely by the quantity of water-vapour held in suspension, but rather by the capacity of the air to absorb vapour from porous materials. When rain falls, after a period of drought, the moisture of the air is rapidly absorbed by all porous substances, clothing, books, woodwork, masonry, and deliquescent salts. The surface becomes clammy to the touch, and continues so as long as the process of absorption goes on. When the rain ceases, and the amount of water-vapour is suddenly reduced, not necessarily by a great amount, the air begins to reabsorb the vapour it had given up to porous substances. Their surfaces are no longer clammy, and although the process of reabsorption may take some time, the air begins already to *feel* dry. The effect of heat on air is to increase its power of absorbing and retaining moisture, while the effect upon timber, clothes, and other porous substances is to reduce the amount of moisture they contain; and when the temperature rises to 212°, they become practically dry. It is thus that during the dampest weather the objects in a room may be made drier, than the condition due to the state of the atmosphere, by introducing a charcoal brazier or a closed vessel of boiling water, which, raising the temperature of the furniture, &c., enables them to drive off or evaporate a part of the water which they had absorbed. Charcoal is preferable to an oil stove, as it contains no hydrogen, and produces no water, but a turpentine drum of boiling water, well corked, *after boiling*, is best of all, as it gives off no carbonic acid.

The effect of increased water-vapour in the air on the human system is to retard the escape of animal heat, and to relax the energies of both mind and body. The pores of the skin are open, but the air does not take up the perspiration freely, and it lodges in the clothing, instead of passing through as in dry weather.

A Relative Humidity of 23 per cent. is, according to Box in his work on Heat, the "dryest" reading that has been obtained in England. The temperature is not given, but there is every reason to suppose that it was not during frost. Compared with Nagpore, where the temperature may be 112°, with 13 per cent. of humidity, it indicates to the Sanitary Engineer a rate of evaporation and other conditions that are quite unknown in Europe.

The mean dampness, in the hygrometric sense, in England, averaging day and night throughout the year, is 82 per cent., and the mean temperature at London being 49·2° F., the average amount of moisture in the air would be 0·51 lbs. of water-vapour per 1,000 cubic feet.

At Bombay, with a mean temperature of 79·13° F., and a mean humidity of 77 per cent., the average amount of moisture in the air would be 1·135 lbs. per 1,000 cubic feet.

The effect of the vapour of water (actually distilled water) on the decomposition of organic matter is of the highest importance: its activity is much greater than that of well or river water, and its power of absorbing gases is greater.

In the form of vapour at the dew-point, its power of absorbing the gases of decomposing organic matter is the greatest, and it may then carry those condensed gases to the lungs of human beings or to plants, as circumstance may determine.

Water-vapour in the air in plains tends to equalise the temperature of day and night: among mountains it has frequently the opposite effect. Being suddenly cooled at a high level, it descends in the form of cloud or mist to the valley or plain, causing a sudden and considerable fall of temperature.

The quantity of water-vapour contained at any time in the air is most readily ascertained by means of the Wet and Dry Bulb Hygrometer, an instrument which illustrates, more than any other, the action of conduction of heat and evaporation from the human skin. The amount of moisture in the air determines the rate of evaporation from the surface of the wet bulb, and the loss of heat from the mercury within it results in a difference of reading between the Wet and the Dry Bulb Thermometer, by means of which the proportion of saturation is estimated.

The following table, prepared to cover the extreme range of readings in India, gives the percentage of humidity, due to differences of reading of the two thermometers, from one degree to forty, and according to a range of temperature extending from 32° to 122° Fah., in increments of 10 degrees, this division being found most suitable :—

TABLE VII.

Of the indications of the Wet and Dry Bulb Hygrometer, compiled from Mr. Blandford's Observations in India.

HYGROMETRIC TABLES FOR USE IN INDIA.

Degrees of Cold in the Wet Bulb Thermometer.

Temperature of the Air.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	33	39	40
	Degrees of Humidity, Saturation being 100.																																							
32° Fah. ...	90	79	70	60	50	41	31																																	
42° ,, ...	92	84	75	68	60	52	44	37	29	22																														
52° ,, ...	93	87	80	74	67	61	55	49	43	37	32	24	19	13	8	2																								
62° ,, ..	94	89	83	78	73	67	62	57	52	48	43	38	34	29	25	21	16	12	8	4																				
72° ,, ...	95	90	86	81	76	71	68	63	59	55	51	47	43	39	36	32	28	25	21	18	15	11	8	5	2															
82° ,, ...	96	91	87	83	79	75	71	68	64	60	57	53	50	47	45	40	37	34	31	28	25	22	20	17	14	12	9	6	4	2										
92° ,, ...	98	95	89	85	81	77	74	71	67	64	61	58	55	52	49	46	44	41	38	36	33	30	28	26	23	21	19	16	14	12	10	8	6	4	2	1				
102° ,, ...	98	94	90	87	83	80	77	74	70	67	64	61	59	56	53	51	48	46	43	41	39	37	34	32	30	28	26	24	22	20	18	16	14	13	11	9	8	6	4	3
112° ,, ...	99	95	92	88	85	81	79	76	73	70	68	65	62	60	57	55	53	51	49	46	44	42	40	38	36	34	32	30	28	26	28	23	21	19	18	16	15	13	12	10
122° ,, ...	99	96	93	90	87	84	81	78	75	73	70	68	65	63	61	59	57	55	52	50	48	46	44	42	41	39	37	35	33	31	30	28	26	25	23	22	20	19	17	16

It may now be noted, with the assistance of the preceding Table, that 82 per cent. of saturation in England, with a mean temperature of 49·2° F., would represent 0·51 lbs. of water-vapour. The same percentage of saturation at Bombay mean temperature (79·13° F.) would represent 1·41 lbs. of water-vapour, or 2·76 times as much.

A very simple form of Wet and Dry Bulb Hygrometer is to be had from Messrs. Kemp & Co., in Bombay, along with the Tables of saturation and weights of water-vapour. This instrument has the advantage, over most others, that if any part of it is broken, it may be renewed without involving the purchase of a new instrument. It was designed for use in mills and factories, and has a large water vessel completely protected from dust or dirt.

The variation of barometric pressure in India has an especial interest in the relation it bears to the rate of escape of gases from putrefying matter. As the discharge of gases from decaying organic matter takes place against the pressure of the atmosphere, which is approximately 14·7 lbs. per square inch, any alteration of pressure will increase or diminish the rate of escape of these gases;

The following Table will show the range of barometric pressure in various places in inches of mercury:—

TABLE VIII.

	Max.	Min.	Range.
London (Greenwich) ...	30·555	28·810	1·745
Bombay	30·094	29·505	0·589
Calcutta	30·233	29·347	0·886
Allahabad	29·961	29·018	0·843
Simla	23·257	22·777	0·480
Nagpore	29·148	28·392	0·856

On Plate I. will be found a curve representing the diurnal fluctuation of barometric pressure, by which it appears that at about 4 o'clock in the morning and at 4 in the afternoon the pressure is at its lowest; and at 10 o'clock in the morning and at 10 at night, the pressure is greatest.

As far as the pressure of the atmosphere is concerned, the fluctuation in the discharge of gas from decomposing organic matter will occur in the above-named places at a rate which will be least at the period of high pressure, and greatest at the period of low pressure.

The above Table gives the extreme range of barometric pressure, which, reduced to inches of water, would be—Greenwich, 23·74; Bombay, 7·936; Calcutta, 12·04; Allahabad, 11·456; Simla, 6·523; Nagpore, 11·633.

Such change of pressure may take place within a few hours, and at Greenwich the air contained in the ground near the surface and for some distance below it would expand, under the reduction of pressure just quoted, to 5 per cent. above its previous volume. Similarly, air and gases in Bombay soil, sewers, or sewage, would expand under the extreme local reduction of pressure to about 2½ per cent. above its previous volume.

There is thus, with every change of barometric pressure, a process of *breathing* going on by which air enters and issues from the ground, mixed with the gases of decomposition, and as the ground in Bombay and in the greater part of India has a temperature at which putrefaction is very active, it is very fortunate for us that the range of barometric pressure is so much less in India than in England. Were it as great, the sewage-sodden ground in many towns would probably become uninhabitable.

Two and a half per cent. of the air in a large sewer of the foulness of those in Bombay, or of the ground air in any large Indian town, is a very undesirable addition to the respirable atmosphere lying along the surface.

Petroleum gas wells of low pressure are curiously affected by barometric fluctuations. With a steady column the gas burns with a luminous flame; if the column rises, the flame is extinguished and air rushes down the tube. When the barometer begins to fall, it returns at first in explosive combination with the gas, then in the proportion to give a non-luminous flame, and finally pure illuminating gas issues as at the beginning. The fire-damp or carburetted hydrogen of coal mines escapes in a similar manner, and barometric changes are carefully watched by the men in charge of the mines.

Each one of the Natural Phenomena, into which we have been examining, is in a state of constant fluctuation, forming combinations that are endless and incalculable; and although a knowledge of their average features is of great importance for the facilities it offers for tabulations, their extreme, and the frequency of those extremes, must be just as carefully noted, if a complete basis for any sanitary work is desired.

After the meteorological survey is complete, and the topography of any town ascertained, there remains to be made a careful study of the people for whose benefit alone sanitary works are undertaken. The point of contact of the people with the sanitary works provided for them will decide, more than anything else, on the utility, and, consequently, on the success, of the reform. In other words, the distribution of the water, the latrines, public and private, the pail depôts, and the sullage discharge pipes, according to the skill with which they are adapted to the ways and needs of the people, will make or mar the popularity of sanitary work in India.

CHAPTER III.

WATER SUPPLY OF TOWNS.

The art of living in organized communities, which we call civilization, has given us few benefits which will compare with that of an adequate supply of potable water. It has marked the zenith of nations whose history alone remains to us, and of other nations whose hydraulic works have survived to tell us that practical sanitation, so far as water-supply is concerned, is many centuries old. Asia is the birth-place of water-works, and many circumstances point to a time in India when the value of a supply of pure water for drinking was much better understood by the people than it is at present.

There can be little doubt that the customs that are still followed by Hindus in the name of cleanliness or purity had their origin in knowledge of the requirement of health that has long since been lost among them.

The present introduction of water works in India is only the revival of an old institution, with the advantages that are to be derived from modern science and manufacture.

Now that statistics of population and mortality are prepared in India, it is easy to observe the alterations in the returns of mortality that follow the establishment of water works in a town. One of the most remarkable cases has been that of the town of Burdwan, with a population of 34,400, in which the death-rate of 42 per thousand, which prevailed before the introduction of the water-supply, was reduced in 1890 to 20 per thousand,

and in the Administrative Report of the Chairman of this Municipality for 1887-88, it is stated that the introduction of a filtered water-supply is the principal, if not the only cause, which has wonderfully improved the state of health of the town (*see* p. 63).

The benefits of a supply of wholesome water in lives saved may be expressed in lives lost by the use of impure water.

Most of the great epidemics the world has known have been most severe in towns where the drinking water was more or less impure, and should any dangerous impurity enter into the source of supply of any water works, it may spread disease and death with fearful rapidity through every part of the town.

A recent and terrible example of how water works may be the means of spreading disease and death took place in Hamburg, the largest and wealthiest port on the continent of Europe, last year.

The Hamburg Water works were established in 1844. They consist of a pumping station and four settling basins. There is no filtration whatever. A medical gentlemen sent by the *Times* as its cholera correspondent to the town reports that originally the basins may have been of some use, but for many years, owing to increased consumption, they have been worse than useless, as the water has no time to settle, but flows in and out, taking a deeper taint from the accumulated foulness of the bed of the basins. Quoting a report published in 1877, he states, that up to the present time the water of the town water works is delivered to the consumers unpurified. When the spring floods arrive, the Elbe assumes a dirty yellow colour, and is quite thick and muddy; consumers receive it in exactly the same condition. Further, the pipes are infested by most of the lower Fauna of the Elbe. In many places, particularly where the current is slower, either because the consumption is less or the pipes larger, they are completely encrusted with mussels and bryozoa, among which small crustacea and worms breed in enormous numbers. Frequently in Spring small eels appear in such masses as to amount to veritable calamity.

Since 1887 things have got worse. To the above should be added snails, crabs, caterpillars, and beetles, with sticklebacks and other fishes.

The state of the cisterns, which are, of course, choked with solid matter, makes things worse; in fact, the chain of pollution grows with every link. The water in the river is cleaner than that of the water works, cleaner in the water works than in the mains, and cleaner in the mains than in the houses. Only one thing was wanted, and that was to provide for the entrance of the cholera poison into the system; and this, too, was arranged. The intake is so situated that the flood-tide passing the sewage outfalls can reach it. To put it graphically, in a Hamburg house the sewage runs out at the basement, and in again at the roof, after taking a tour in the river and the water-works. The settling basins are particularly filthy fish-ponds, containing muddy water, slimy weeds, a peculiarly offensive greeny black deposit, and shoals of foul-feeding fish.

The cholera epidemic has cost the town 8,000 lives, and paralysed its commerce for a time with the whole world.

New water works have been planned on a very extensive scale, and will occupy two large islands on the river.

The intake is to be moved about a mile and a half higher up, while one island will provide space for settling tanks, and the other will be occupied by 20 filter-beds. The existing basins are to be used as reservoirs for filtered water—after being cleaned and lined—it is hoped. From what has been said of the state of the pipes, it is likely that the greater part will have to be re-laid, as it is doubtful if any of the appliances used for pipe-cleaning will be able to remove the incrustation. Altona, which lies a few miles below Hamburg, escaped with a comparatively trifling visitation of cholera by virtue of having properly arranged water-works, although the river water passing it must be more impure than that which arrives from above at Hamburg.

Another example of the fouling of the water-works supply by sewage occurred at Cairo in 1886. The Cairo Water works belongs to a French Company, working under a concession giving it the exclusive right to supply water to the town for any purpose for a period of years, extending well into the next century. The water, which is pumped from the Nile, is taken *at*, and not *above*, the city. A drain built expressly to serve the botanical garden within the city, and not for sewage, discharges into the river a short distance above the intake of the water-works.

Cairo is not yet sewered, and all its nightsoil goes into cesspits underground, built, at the lower part, in open masonry, so that all soluble matter may wash through into the subsoil of the town. At times these cesspits become blocked and require to be pumped out, and it happened that one of them, of about 200 tons capacity, became full, and the owner applied to the *Société de vidanges inodores* for an estimate to empty it. This

Company has a service of vacuum carts which carry cylindrical air tight tanks for the transport of sewage. The tanks are exhausted by means of a vacuum pump driven by steam at a central depôt, and, on arrival at the cess-pit, a hose is dropped into the liquid, and the tank fills itself by means of the pressure of the atmosphere on the surface of the sewage in the cesspit.

As there is a perfectly clear way through the hose into the tank, a much thicker liquid may be made to pass than if the pipes were obstructed by valves. The vacuum carts transport nightsoil through the town at all hours, without any nuisance.

The Company, knowing from experience that when a cesspit becomes congested there is generally much more to remove than the simple contents of the chamber, on account of what will flow back into it from the surrounding ground, submitted an estimate that was not acceptable to the owner, so he, with or without the official consent of the *Voirie* (corresponding to our conservancy department), made an opening into the Botanical Garden drain, which passed near his house, and, with a contractor's pump, discharged some 250 tons of putrid sewage, through the drain, into the Nile, just above the intake of the water-works.

The mortality of the town, always high, rose promptly to over 60 per thousand, and the pipe-water, if allowed to stand for 24 hours in a bedroom jug, began to form a scum and to smell very foully. It was officially reported at the time that, as good filtering sand is very scarce in the neighbourhood of Cairo, a filter had recently been filled with sand of an old graveyard, from which bones had been separated by screening. We may presume that the sand was washed before being used.

No action was taken by the Government against the proprietor of the cess-pit in question.

In July 1882, immediately after the bombardment of Alexandria, the water-supply of the town, which had just been occupied by British forces, was cut off by Arabi, who built an earthwork battery across the Mahmondieh Canal, thus cutting the town off from the mainland. This canal joins the Rosetta branch of the Nile at Atfeh, some 22 miles from its mouth, and brings the whole of the fresh water-supply to Alexandria. When the canal-supply was cut off, all the water that reached the town was what came into the five miles of bed between the battery and the water-works pumping station. That part of the bed next the camp was used as a depôt for the refuse of the camp, and the quality of the water reaching Alexandria suffered in consequence. In order to render it fit for drinking, the Engineer of the Water Company, Mr. J. E. Cornish, used a mixture of permanganate of potash and hyposulphite of soda, which he suspended in a bag in the channel leading from the pumps to the filters. The bag was enveloped in several other bags, so that the solution of the salts should take place slowly. The precipitate of organic impurities caused by the salts was retained in the sand filters, and the health of the town was unusually good all through the time of siege, which continued during the hot rainless weather until September, when the battle of Tel-el-Kebir on the 12th destroyed the rule of Arabi, and caused the immediate abandonment of the battery and camp on the canal at Kafr Dowar.

Two instances are on record of sea-water being mixed with the fresh water in the service pipes of cities. The first took place in 1885, when a very low Nile allowed the salt water of the Mediterranean to advance along the bed of the Rosetta branch of the Nile delta to an unusual distance inland. In this year it went past the inlet of the Mahmondieh Canal, which is filled by steam-pumps during low Nile, and the water pumped was a mixture of the fresh water flowing on the surface of the stream, with the salt sea-water lying at the bottom. The amount of salt in the water supplied to the town, although sufficient to be noticeable, was not enough to be unwholesome. It ceased altogether when the river began to rise.

The second case occurred in Calcutta in 1891, before the monsoon, when the volume of the Ganges was at its lowest. Sea-water from the Bay of Bengal, owing to the reduced volume of the river, flowed up the bed to the intake of the water-works, bringing with it a quantity of small marine snakes which were recognised by their flattened tails. The appearance of the snakes at stand-pipes and private water-taps in bathrooms first drew attention to some derangement in the supply. The filtered water-reservoir was emptied and examined by a Committee of the Municipal Board, but no snakes were found in it. How snakes could get from the river into the pipes without passing through the clear water-reservoir has not been explained, although it is hard to imagine how those in charge of the works could fail to know exactly how it all occurred.

The two cases just quoted refer to water-works supplied from rivers whose waters are largely used for irrigation. In both, the volume required for irrigation is steadily increasing, reducing the flow at the mouth, and also the volume along their course. In establishing water-works upon such rivers, the influence of reduced supply must be taken into account, whether it be with a view to avoid pumping sea-water, or to provide against the contamination due to drainage or other causes which in rivers is generally greatest at the time of smallest volume.

It is possible to establish water-works giving a considerable supply of water and yet to benefit very little by the outlay.

The Cairo Water-works supply is at the rate of 15·23 gallons of water per day per inhabitant. No part of it is taken for flushing sewers, as sewers do not yet exist there.

All the water, after being used by the inhabitants, is thrown into cess-pits, where it meets with the solid and liquid excreta, and promotes putrefaction. It carries the putrid sewage all through the foundations of the town, and up to the surface in places, where it evaporates into the air. It also carries the sewage into wells which are still used for drinking purposes. Many of these wells are surrounded by soil blackened by sewage, and when a street is opened for the laying or repair of gas or water-pipes, the stench from the ground compels the inhabitants to close their doors and windows.

The mean annual temperature of Cairo is 70·15° Fah., and the maximum range in twenty-one years is from 117° in 1881 to 28·4 in Feb. 1880. The underground temperature must approach the mean of the season, and must be generally far above that temperature (55°) at which active putrefaction is said to commence.

Cairo stands in a province noted for the purity of its air and for its low death-rate. In the five years 1880—1884 the death-rate in the province of Gizeh was 19·59 per thousand (excluding the cholera year of 1883). In Cairo it was 44·77. Including the cholera year, the figures are increased to 22·53 and 48·01.

Out in the province there are neither water-works nor sewers, the population living in small villages; the race is the same as that living in the town, and the difference is due to the accumulated filth among which the citizens are obliged to live. Cairo, with its crowded narrow streets, its unclean habits, and its underground honeycomb of cess-pits, profits very little by the wonderfully pure air that surrounds it. Sulphuretted hydrogen gas can be distinguished in almost every house, not excluding the palaces and public offices, the result of decomposing sewage, aided in its putrefaction by the water-supply. Numerous deaths have occurred among the workmen employed in emptying the worst of the cess-pits, and the infant mortality, which doubles during the hot months of June till September, is largely attributable to the emanations from putrid sewage which escape so freely into the dwellings.

Nile water taken well above Cairo has been found, after the removal by settlement, or filtration of the alluvial mud it always carries in suspension, to be very pure, soft, and wholesome. The supply for Cairo is not only drawn at a point below several sources of contamination, but has the disadvantage of a current in the river that falls as low as 3 inches per second, and for half the year will not exceed 12 inches. As if the combined impurities of the town were not sufficient, it was the custom, not very long since, to deposit the contents of cess-pits, for economy of cartage, on the nearest waste ground, within or near the walls. This work, when open carts were used, was carried out at night, and under no proper supervision.

To the south of Cairo are mounds of rubbish of very great extent, containing much building-material, pottery, and charcoal. A section was made through one of them while cutting a road, and it was observed that the charcoal lay in layers, alternating with building-materials, indicating clearly the remains of a succession of towns of which no history remains. A vague tradition ascribes the repeated burning of the ancient Cairo to the results of successive visits of the plague, of so terrible a character that the town was each time abandoned. The destruction by fire in this case would naturally follow, if thieves and nomads were among the first to re-occupy it. This tradition, if true, finds a parallel in the changes of site that have occurred to Indian towns, brought about through overwhelming epidemics, the result of accumulated insanitary conditions. From the foregoing remarks on existing water-works, it is evident that if a real benefit is to be obtained from a water-supply in towns, the source of supply must be most carefully chosen, and the distribution must be most jealously watched in the interests of the community at large.

Up to the present time a good water-supply may fairly claim to be the most important sanitary agency in India, and when we consider the perverse ingenuity with which Indians of all classes defile their sources of drinking water, it becomes evident that special precautions are necessary to protect them.

Rivers, tanks, and wells supplying drinking water are used for bathing, washing of foul and often of infected clothing, and of vessels of all kinds, while at the same time the rivers and tanks are used by cattle for bathing.

Wells are poisoned by rotting vegetable matter, by leakage of surface water, and sewage; and even when every precaution has been taken for their protection, any one may bring a foul vessel to draw water, and thus introduce the elements of contagious disease. Every separate source of potable water-supply in a town is thus a source of possible contagion, and as the habits of the people in this respect are not likely to change for many generations, it is of the utmost importance that the town should be supplied from *one* reliable source, out of reach of the people, and that the water should be conveyed to them in pipes, so that they may not be able to contaminate it. In a small and poor town, a supply of potable water might be possible and practicable, while a larger supply to cover street-watering and sewer-flushing might be beyond the means of the community. The old source of water-supply from wells or tanks is always available for conservancy purposes after water-works are established.

The sources of potable water-supply in India are reservoirs, filled during the rains, rivers with a constant stream, canals and wells—of the latter both the filtration well and the Artesian well are used. Taken in order of purity of these waters, the list would have to be reversed, but the Artesian well-borings have been so uncertain in their results in India that other sources of supply have of late received more attention. Several successful small borings have been made in Quetta, and additional wells are being made. Probably the most promising boring in India is that at Port Canning, near Calcutta; it was made under circumstances that at first promised very little success. It was carried out by Mr. F. J. Agabeg, for the Port Canning Land Improvement Company, which has an estate of over 100,000 acres of salt marshy land very badly supplied with potable water. Much of the land would be submerged at high-tides, were the sea not kept off by embankments.

The ground, as described in *Indian Engineering* of the 14th October 1887, is alluvial, and was said to be of that quality for 700 feet. For the first 126 feet, the sinking of the well-tubes was much retarded by silting, which rose on one occasion to a height of 50 feet in the tube. The sand was passed through at a depth of 126 feet, and at 173 feet pure and fresh water rose to within 8 feet of the surface from a bed of micaceous sand.

At the present time this well is 485 feet deep, and has tapped a spring of water which flows at the rate of 90 gallons per hour. The height of the water in the pipe varies from six inches to three feet below the ground level, according to the position of the tides in the Bay of Bengal. The water is reported good and drinkable. The cost of the well at present may be taken at Rs. 10,000, exclusive of the cost of the machinery employed for boring. The tube is still being sunk in the hope of reaching a water-supply that will overflow.

The Artesian boring at Lucknow is the deepest that has yet been attempted in India; the boring reached 1,336 feet before it was abandoned, and the pipes with which the boring was lined ranged from 12 inches in diameter at the top to 3 inches in diameter at the bottom. A careful record of the boring was kept, and samples of every foot of the soil passed through have been preserved in a cabinet for future use. The entire formation passed through is alluvial, consisting of sand, clay, and frequent beds of kunker. The sand varies much in quality, and is in places much mixed with mica. There was little uniformity in the material passed through, but the last 115 feet formed an almost uniform bed of tenaceous clayey silt, quite compact, and apparently of the right consistence to be wholly impervious to water. At 1,264 feet the 3-inch pipe could be forced no further down, and at 1,336 feet the sides of the bore-hole fell in and stopped further boring. The Engineer in charge of the work, Mr. H. G. Trowbridge, an expert in such matters, was of opinion that below the lowest bed of clayey silt a good water-supply might be found, and he proposed to make a second boring 2,000 feet deep, beginning with pipes 24 inches in diameter, and terminating with six-inch pipes at the bottom. His estimate, based on the experience of the first well, was Rs. 90,145, and the time required for the work from one-and-a-half to two years.

The absence of exact knowledge regarding the geological section over the greater part of India gives to Artesian boring a very large element of uncertainty, and the very mediocre success of the work already done has not encouraged municipalities to speculate in well-boring. Such an immense depth of a continuous soft alluvial formation as that pierced at Lucknow has been, probably, heretofore unknown in Artesian well operations. In such a formation a well must, of necessity, be lined from top to bottom with iron-pipe, and as no one size of pipe can be driven beyond a limited distance, on account of the friction of the bore-hole, it is necessary to begin the well with a pipe of large size, and when it is driven as far as possible, to insert the next smaller size that will pass the first one, and drive it as far as it will go; and so continue till the smallest practicable size has been inserted or the desired depth is reached. Under these circumstances, the limit of the existing well was reached at 1,336 feet with a 3-inch bore-hole.

In order to obtain an Artesian well supply, it is necessary to find a supply of water below an impervious stratum, and the supply must have its source at such a height—it may be many miles away—as will cause the water to rise freely to the surface.

A good Artesian well supply has such valuable advantages over any other in India that the money spent in the careful and systematic search for water by boring, until absolutely positive or negative results are arrived at, is well laid out. The results may be determined by purely mechanical limits, or by touching primitive rock. The question as to how a survey of such national importance should be paid for is open to a good deal of debate; it does not, however, enter into the objects of this book. All the uncertainties of contamination are avoided in an Artesian well supply, and the cost of filtering and of filters is saved. Algeria was the first country to benefit on a large scale by the use of Artesian well water for irrigation. California has also made extensive use of Artesian wells for the same purpose. It is highly probable that India contains large tracts of land where Artesian borings would produce all the water required for the service of towns.

In Lucknow the Artesian well project has been abandoned, no doubt after mature consideration, and water-works are now in course of construction, to use water taken from the Goomtie at a point above the town.

It is necessary for the success of an Artesian well that the water should rise well above the surface of the ground, otherwise the pressure below will not be great enough to pass a sufficient quantity through the comparatively small pipe at the bottom of the well. If a supply of 2,000,000 gallons had to pass in 24 hours through the bottom of an Artesian tube 5″ in diameter, the velocity per second of the water would not be less than 27·23 feet. In the instances just quoted, there was, doubtless, plenty of water in the stratum reached by the pipes, but the pressure was not sufficient to bring the required quantity per day to the surface. Digging a deep well around the bore-hole into which it might discharge would greatly increase the delivery of water, but the cost of pumping the water to the surface might make the supply dearer than that of some other available source.

Damascus possesses, in all probability, the oldest working water-works in the world. The city itself is the most ancient of existing cities, having seen the rise and fall of the Greek and Roman empires, of Babylon, Nineveh, Palmyra, and Jerusalem. When taken by the Saracens from the Romans, the water-works already existed, and it is probable that the latter people constructed the works which still exist and supply the town. Damascus lies in a valley on the river Abana, which flows from the Lebanon Hills, and is lost in the desert to the east of the town.

The water of the river is led through the town by covered masonry conduits at a slight head of pressure, and overflows into basins or tanks in the courtyards of the houses. From the basins it passes to a second series of underground channels, which serve as sewers, and convey the water to the desert on the east side of the town, where it forms an offensive marsh, and is finally evaporated. There are wells on the course of the clear water channels for the supply of the poorer classes, but the distribution of water is very unequal, the greater part being wasted by the wealthy or the official class.

In spite of a copious supply of excellent water, Damascus has had no more immunity from epidemics than other Eastern cities. The double canalisation for water-supply and drainage being more or less leaky, saturated the soil and raised the spring level nearly to the surface. So, although the beauty of the gardens in and around it have not been exaggerated by travellers, Damascus is, and always was, an insalubrious town. These sewers are rarely, if ever, cleaned, systematic ventilation of the sewers is unknown, and, as they pass below many of the houses, their influence must be exceedingly unhealthy. The direct openings from the houses into the sewers used to be found very convenient for the disposal of dead bodies of murdered persons. Once in the sewer, no one could say how or when the body got there.

The Beyrout Water-works possess a method of distributing water which seems to be well suited to the place. The water is obtained at the Dog River, about three miles to the north of the town. It runs first into settling tanks, where it deposits a small quantity of fine sand, and is then pumped by turbine power to a covered reservoir which dominates the town. The town of Beyrout lies on the slope of a hill rising from the sea, and iron-pipes convey the water-supply to masonry cisterns in the houses, which receive a constant supply. The quantity of the water given to each house is regulated by a disc fixed within the pipe having a small orifice, which is adjusted to give a fixed number of gallons per day when running constantly, and rent is charged according to the size of hole in the disc. As pressure varies at different depths below the reservoir, the size of hole has to be varied to give the same quantity of water in different parts of the town. All water for gardens is sold by meter. By this method of distribution the people pay for whatever quantity of water they get. In spite of the settling tanks, and the apparent clearness of the water, there is a certain amount of wear in the orifices due to friction of solid particles, to corrosion, or to both causes, which, if neglected, would increase the supply beyond the stipulated quantity. Various materials were tried with a view to getting a disc that would not wear, including various metals and ebonite, but those which resisted corrosion best were not hard enough to bear friction. A small glass bend was tried, set in a disc of copper, with what result the author has not learned. A strainer is needed, when the water-supply is very small, to protect the orifice from accidental fouling. An enlargement of the pipe against the disc is also useful, which slackens the current and lets solid matters precipitate.

Aurungabad has, at present, its largest supply of potable water from an infiltration gallery 9,400 feet long, having a width of from 2 to 3 feet, and a height varying from 6 to 10 feet. The floor is 12 feet below the bed-level of the river Ursool, which flows by its side. The roof is a brick arch, supported on the porous trappean rock, in which the gallery is excavated. Shafts or man-holes communicate with the surface at intervals of from 200 to 300 feet. This work was executed during the minority of the Shah Jehan, in the 16th century, by Malik Umber, the Regent and Prime Minister. It was subsequently added to, and improved by, the Emperor Aurungzebe, in whose time the City of Aurungabad is said to have contained 300,000 inhabitants.

Communication between the gallery and the town was made by means of an open channel and earthen-pipes, which discharged into cisterns in various parts of the streets of the city. In March 1886, the infiltration gallery, having been cleared out, the discharge was gauged and found to yield 1,705,536 gallons in 24 hours, which is equal to 34·1 gallons per head for the present population of 50,000. Owing to the dilapidated state of the ancient conduits, there is much loss by leakage on the way to the city. Cast-iron mains and a storage tank have been proposed by the Divisional Engineer, Mr. W. Marrett, and when these works are completed, Aurungabad will receive from the head-works of Shah Jehan and Aurungzebe a copious supply of the purest water at all seasons—a supply that will be safe from all contaminations.

The water-supply of Lahore is taken from the river Ravee, at a distancc of about two miles from the city. The water is obtained in four supply-wells sunk in the bed of the river. The wells are 20 feet in diameter and 43 feet deep; their maximum supply is 900,000 gallons per day of 24 hours, and the population for which the supply was estimated was 130,000. The maximum supply is, therefore, at the rate of 6·92 gallons per head per day. The works were opened in 1881, and although there were some manifestations of caste-prejudice at first against the pipe-water, the public soon learned to appreciate its value and convenience. The average mortality for five years previous to the opening of the Lahore Water-works was 39·0 per thousand in city and suburbs, or 49 in the city and 29 in the suburbs. In 1885 the mortality in the city was reduced to 36, while that of the suburbs remained at 29 per thousand, making a total average of 32·5. In 1891 the average for both was found to be 32·37.

Lahore has no underground drains, and the existing surface drains are not all that could be desired. All the old sources of water-supply are still in use for washing, irrigation, street-watering, &c., and there is no doubt that much impure water continues to be drunk. The reduction of mortality in the city from 49 to 36 per thousand, within the space of five years, accompanying such a small supply of good water as is represented by 6·92 gallons per head, is a valuable testimony to the effect of good drinking water on the health of a town.

Alibag, a small fishing town on the Western Coast, 24 miles south of Bombay, had, previous to 1887, a very bad water-supply from surface wells, which were necessarily shallow to avoid the infiltration of sea-water. Towards the end of the dry season the water became impure and brackish, and much sickness resulted. Since the opening of the Alibag Water-works only sporadic cases of cholera are known, and the annual visitation has ceased altogether. The general health of the town is immensely improved.

The water-works consist of a reservoir of 7 acres, with a maximum depth of 20 feet. A 9-inch stoneware pipe carries the water-supply to the town, a distance of 1½ miles. The water is distributed in public wells, which have been cleaned out and lined for the purpose, but being open to the sky they are liable to be fouled by rubbish thrown into them, or by vegetable growths. The cost of the works was Rs. 46,256, or Rs. 7·85 per head on the present population of 5,886, and the supply is 61,643 gallons of water per day, or 10·4 gallons per head. Much of the cost of the works was defrayed by donations.

Ahmedabad draws its present water-supply from the Sabarmatti River, at Dudheshvar, by means of one well sunk in the bed of the river, and covered with an arched roof carried on rolled iron beams. Entrance is obtained by means of a man-hole. The well is 25 feet in diameter and 12 feet deep, and is sunk in an immense bed of sand. It was tested in February 1888, and delivered water at the rate of 1,250 gallons per minute, with a reduction of level of 3 feet, and, with the pump employed, no further reduction of level could be obtained after 23½ hours' continual pumping. The rate of current in the well was 24·4 feet per hour. It was described in the report of

Mr. J. Strachan, M.I.C.E., as the intake from a flowing stream supplied through a filter-bed many miles in area.

The population of Ahmedabad is 130,000, and the present supply is at the rate of 10 gallons per head per day. The history of the water-supply in this city is a long one. It began in 1847, when the first water-works were constructed. A pumping-engine was placed on the river below a nullah which drained half the town, and water was supplied at the rate of less than one gallon per head of population. The settling tanks were so small as to require filling twice daily, and the filter-beds were only equal to half the supply of the pumps. The distributing pipes were of soft, porous, unglazed earthenware, set in masonry with large, old-fashioned masonry air-shafts at intervals. These shafts acted as safety overflow-openings. The situation for the pumping station was chosen on account of the depth of the water close to the city walls, but being below the town the quality of the water was worse than that of any of the wells, and was pronounced by Dr. Lyon, the Chemical Analyser to Government, to be totally unfit for potable purposes. The death-rate before the new supply was laid on was 49·07 per thousand. The present death-rate is 35·93.

A project and estimate was made in 1874 to supply the town with 10 gallons per head per day through a 24-inch earthenware rising main against a head of 50 feet pressure. The estimate was Rs. 5,00,000. It is only remarkable for the proposal to submit 24-inch earthenware mains to a 50-foot head.

Another scheme in 1878 was put forward by the then Collector, who, for a sum of one lakh, proposed to obtain more powerful engines and pumps, make larger storage tanks, improve the filtration, and to extend the pipes to every part of the town. The Sanitary Commissioner, fortunately for the town, refused his sanction to this project.

In 1878 the Executive Engineer for Irrigation proposed to bring water in mains from a purer source to the existing pumping station, carrying the supply, part of the way, in iron-pipes bolted along the city wall for 4,000 feet; the rest to be of earthenware. The supply was to be 10 gallons per head, and the estimate Rs. 2,84,760, but as the pumping plant and distributing mains would only distribute less than one-tenth of that amount, the project was rejected.

Several other schemes were proposed and rejected, until Colonel Ducat was called to report on the water-supply and prepare a project, which has since been carried out, along with a sewerage scheme, which is also carried out, but is not yet in use. The 10-gallon supply of water is quite inadequate to convey the sewage of the town away to the outfall. The sewers are, doubtless, awaiting an increased water-supply which the present works are capable of giving.

Ahmedabad has wisely decided to dispose of its waste water and sewage on cultivated land, and 14 acres are already under treatment without causing any nuisance. The soil around the town is well suited for sewage irrigation, being porous and loamy.

Since the first pumping-engine was put down at Ahmedadad in 1847, the science of water-supply has made immense progress, and the final utilisation of the water for irrigating and distributing the town sewage on cultivated land, instead of polluting a river with it, will, it is to be hoped, remove the reproach of indifference to sanitation from the town, and prove as profitable as the sewage farming at Madras (*see* p. 147).

Pumping Machinery for Water-works.

In the choice of pumping engines for Indian water-works, certain considerations occur that may be neglected in England.

Pumping machinery is not yet made in India, although the time is not far distant, when, between mines and water works, there will be work enough to encourage local builders. Neither mines nor water works can continue to depend on Europe for repairs, which must be done in the country, and repairing leads eventually to the construction of new machinery.

During the past twenty years a great change has taken place in the style of pumping engines. Large cylinders and pumps, long strokes, and slow speeds were the rule. The machines were ponderous, the vibration great, and heavy foundations were necessary. The continuance of this type for so long was probably due to a fashion of making large and heavy valves in the pumps, which had to be opened and closed with care to avoid accident. The slow and heavy beam engines were first abolished in factories as motors, in favour of quicker running and cheaper horizontal engines. The quick horizontal engine was next connected, by toothed wheels, to the slow running pumps of the old pattern, and finally it was discovered that by making the pump valves light and numerous, the pump could be driven as fast as the engine. The pump rod was then connected direct with the piston rod of the engine, and a smaller, more compact, and cheaper machine was the result, which at first became popular in mines on account of its handiness, although in point of fuel economy it would not compare with the old type of engine. By improvements in the mode of using steam, notably by the employment of triple expansion, the modern high speed direct acting pumping engine is competing successfully with its ancestor, the beam engine, and one of the most significant facts connected with the new development is that one of the oldest and best known builders of the beam pumping engine, Messrs. Jas. Simpson & Co., have abandoned it in favour of the Worthington Pumping Engine, which has already a good reputation in India at Bombay, Calcutta, Delhi, and Poona. It is hardly to be expected that this machine will ever beat the recorded *duty* of a first class beam pumping engine, but the comparative smallness and lightness of its parts, offering great facility in transport, and economy in renewals, also the smaller space requisite for housing it, are undoubted advantages which belong to its class. We may, therefore, expect that improvements in the future will be more in the direction of this type of engine than of any other.

The choice of boilers seems to lie between the Lancashire Boiler (for coal fuel), the Cornish (for wood), and the Babcock and Wilcox, which will burn any fuel, and which, being divisible, has great advantages in facility of transport. All towns that have or that require water-works are not approached by rail, and the bridges on the roads leading to them were not built with a view to the passage of anything heavier than an elephant. The transport of a full-sized Lancashire Boiler, to work at 150 lbs. per square inch, say along the 52 miles of road leading from the railway at Nandgaon to Aurungabad, and crossing 50 bridges and culverts, would be too costly to be attempted. Babcock Boilers were transported along this road without mishap. In comparative trials between this and the Lancashire Boiler, their evaporative powers were found to be so nearly the same as to entitle them to be regarded as equal. The Babcock, however, could get up steam more quickly, and its grate area is so large as to allow any fuel to be burnt with advantage. The Babcock Boiler may, therefore, be considered as similar in steaming powers to the Lancashire, and easier as well as cheaper to transport by sea or road. With regard to a tendency to scale and the facility for cleaning out, the same rule applies to all boilers for raising steam.

All deposits which adhere to the interior surface of the boiler should be separated *before* the water is pumped in, as the efficiency is rapidly reduced with even a thin scale. A deposit of $\frac{1}{16}''$ of lime scale on the interior surface of a boiler will increase the fuel bill by 15 per cent. Scale not only increases the fuel bill, but, by retarding the passage of heat through the plates, makes them needlessly hot. Steam at 90 lbs. pressure requires the water to be heated to 323° Fah. The boiler plates would need to be heated about 6° more than this, but if $\frac{1}{2}''$ of scale were formed on the plate, it would require to be heated to over 700°, which would ruin the boiler.

Indian municipalities, like Indian individuals, are very liable to be influenced by low price in the choice of their waterworks machinery, regardless of quality, and British manufacturers, when they know that competition will be very keen, are strongly tempted to offer a cheap installation, as the only likely way of getting an order. Pumping machinery is a comparative novelty in India, and its management requires training like that of the marine or the mill engine. The guarantee generally required for the working and maintenance during a certain period is, under the circumstances, an excellent precaution, which, if fairly carried out on both sides, could not well be improved on. Guarantees regarding fuel must, of course, be based on a very clear understanding as to what the particular fuel to be used will do. Testing with English coal is best where that fuel is intended to be used, but in the interior the test should be made with local fuel, and if a boiler can be found in the district using the same fuel in a manner satisfactory to the purchaser, its duty in water evaporated might be taken as a standard to which the guarantors of the pumping machinery would not be likely to object.

In the housing of pumping machinery, except in certain special cases, the utmost simplicity in style of buildings should be sought. Protection against the weather and against dust are the first consideration, coupled with liberal ventilation on account of the workmen. Men can support a much greater heat in a moving than in a stagnant atmosphere. Ample space should be provided around the various parts of the machinery likely to require attention, and the facilities for lifting, moving or changing any part in the shortest time, and with the smallest amount of skilled assistance, should be most carefully studied by the Engineer of the works.

Chimneys should be circular in section from top to bottom, resting on a circular foundation, so that the stability may be equal in every direction. The fashion of building chimneys in imitation of a solid column, to which they have no relation, dies hard in India, where builders copy each other. It has often been observed that chimneys give way very frequently in the plinth where the mass of masonry is greatest and the quality of workmanship the worst. The top of boiler chimneys in India should always be protected by a cast iron cap, with its upper surface sloping at an angle of about 27° with the horizon, to deflect the wind. The cast iron cover is necessary to protect the hot brickwork on the top of the chimney from the action of the heavy rains of the monsoon, which have a destructive effect on the bricks. The cover should be cast in pieces of such a weight as will allow them to be lifted easily through the chimney and bolted together. The lightning conductor may be attached to any part of the cover. The flues between the boiler and the chimney should in India be always *above ground* in order to avoid the risk of percolation from the rain. They should be roofed over with sheet iron on the top to protect the brickwork. There are factory chimney flues in Bombay, which, having been built underground, have occasionally, during the monsoon, to be pumped out on account of infiltration. The flue of a factory is certainly no place for raising steam.

The boilers of a municipal pumping engine having no sudden change of draft of steam, such as happens in woollen factories or ironworks, are well suited for mechanical stoking, particularly when they can use small Indian coal. Even distribution of fuel on the bars and a uniform draught in the flues contribute largely to economical working both in boiler and engine rooms. Pumping engines are not, as a rule, provided with governors, so a fluctuation of steam pressure is followed by a change of speed of the engine, unless it is promptly attended to by the man who is erroneously supposed to be always on the alert in the engine room.

A pump cannot be too near its source of water supply. Every yard of suction pipe brings a force to act on the under side of the valves that has no place in the calculation of the pump. Builders of pumping engines are not always told of the intended length of the suction pipe and serious accidents have followed in consequence. In 1872 an underground pumping engine was twice disabled in one of the collieries of Messrs. Bell Bros. of Middlesboro, through the bursting of the lower chamber of the pump, and two new valve boxes were successively supplied. Nothing was said of the cause of the accident until an agent of the maker visited the pit and found about 40 yards of suction pipe attached horizontally to the pump. This horizontal part of the pipe contained 1·4 Tons of water, whose motion was stopped each time the bottom valves closed, and the hammering it caused ruptured the lower chamber of the pump. An air chamber was put on, and the difficulty ceased. Pumping engines established upon Indian rivers have to work, at different periods of the years, with a level of water in the river that may vary to the amount of 26 or more feet. It would be impossible to place a pump at this height above low water without a considerable sacrifice of efficiency. It is best, when possible, to divide the fluctuation of water level and place the pump with the suction valves at half the height of fluctuation. The lower valves will then work, during low water, with a partial vacuum equal to half the height, and during high flood with a bottom pressure equal to half the height of fluctuation. This must be considered during the designing of the pumps, as for effective working the valves should close promptly at the end of the stroke, and allow the least possible amount of slip. To arrive at this object, some change in the closing power of the valve might be made twice a year, either by adding and removing weight, or by altering the tension of the closing springs.

A very perfect but rather expensive type of pump is in vogue in Germany, attached to a fly-wheel engine. The valves are opened and closed by means of a cam which is designed to give the valves such an amount of opening at every part of the stroke as to secure an unvarying velocity of current through the opening. This pump works silently, and gives the highest possible efficiency.

It would work equally well with every position of water level, above or below the pump, as the valves do not depend, for closing, upon the water. The actual possible duty would, of course, vary with all depths of water level below the pumps.

Pumping from a river, subject to periodical high floods, when the water is loaded with silt and grit, causes excessive wear on the working parts of the pumps exposed to the water. It is, therefore, most desirable to have an interval between the pump and the river, in which the water may deposit the heaviest part of the silt, and thus save a good deal of abrasion. Opinions are divided as to the best style of pump for this kind of work, but the horizontal pump, with internal plunger, working through a midfeather diaphragm, has done very good work, and appears to offer the smallest amount of lodgment for grit against the working parts. The horizontal piston pump is the type which suffers most, as coarse grit may be carried in by the current of the suction pipe and valves, and once in the cylinder, cannot be expelled on account of the slower velocity of the current there. No leather must be used about the valves and packings of a waterworks pump in India on account of the religious prejudices of the Hindu population.

The use of high pressure steam follows the same rule in India as elsewhere. Good wrought iron and mild steel will, according to a series of careful experiments made by Mr. Daniel Adamson, increase in strength up to 450° Fah., which corresponds to steam pressure of 382 pounds on the square inch.

A steam boiler is, therefore, stronger when in steam than when cold. The real limit of temperature of steam, and consequently of working pressure, is the heat-resisting quality of the lubricant used for pistons, valves, and rods. As long as tallow continued to be used in steam cylinders, high pressure steam decomposed the fat and set free an acid that attacked all the metal surfaces with which it came in contact. It was particularly destructive to wrought iron bolts in pistons. Rape, Colza, and Gallipoli oils were still worse in their effects. The advent of pure mineral oils, in which tin might be melted without boiling, did more than anything else to give practical effect to the use of high pressure steam, and repairs to cylinders, pistons, and valves are now much less frequent than they used to be. Mineral lubricating oils are now to be had of every quality in Bombay and Calcutta.

Distribution of Water.

As the distributing pipes of waterworks cost more than all the rest of them, their arrangement and proportions demand the greatest care on the part of the engineer. Their weight and size are decided on consideration of the pressure they must bear, and the volume of water that must pass through them in one minute at the period of greatest probable consumption. The volume of supply is based on the actual requirements of the people for drinking, cooking, and washing, plus a larger quantity which provides for conservancy, manufacturing purposes, and waste. The waste generally amounts to one-third of the whole. The smallest amount of water with which a town can supply all its needs, without affecting the public health, is probably not yet known, as municipalities in India are peculiarly averse to economies in water supply that would involve the use of meters. The waste of water that is at present provided for has already involved the outlay of very large sums which might have been saved with better administration. The exterior wear of pipes depends principally on the amount of salt the ground contains. This is not limited to towns on the sea coast, as at Agra the amount of salt contained in the ground has been known to destroy a one inch wrought-iron pipe in about one year. Galvanizing is of very little use to protect pipes from salt ground. A good coat of asphalte or bitumen protects them better than anything else. This coating is much used by French companies to protect gas pipes. The turned and bored joint has largely superseded the lead joint in pipe laying, the lead joint being now used principally on curves and for joining up pipes that meet when coming from different directions. The rapidity with which turned and bored points can be put together has contributed to render them popular. They are capable of a good deal of lateral deviation without leaking. Opinions differ as to how much alteration in length takes place in lines of pipe after they come into use, and in what way it should be compensated. At first the pipe has a length due to the temperature of the ground; when put to work, it will acquire the temperature of the water passing through it. If the work is intermittent, it will be influenced by the ground temperature, and so on. Contractors who have been used to the repair and maintenance of water pipes state that however well pipes may be laid at first, there is a movement that in time will produce a leakage of sufficient amount to require attention. Good glazed earthenware pipes laid in a suitable concrete bed, in solid ground, make an excellent water conduit that is much less liable to interior fouling than iron. Earthenware pipes have, however, very little elasticity, and the great number of joints they must necessarily have increases the risk of leakage.

They are not suited for any but very low pressures, but their cheapness is a strong recommendation in poor communities like that of Alibag (p. 54), where a population of 5,886 persons has a water supply laid on to public wells in the streets at a total cost of Rs. 7·85 per head, including the cost of a storage tank.

It is natural for people on having a supply of good water brought into their houses, or, at least, into their streets, and delivered above ground level, to waste as much of it as they possibly can. Every reasonable precaution must therefore be taken to prevent waste. Self closing cocks should invariably be used, except in cases where the supply is by meter. As in the case of pumps (p. 63), no leather must be used in the construction of cocks used on stand pipes or elsewhere for drinking water, as the contact of leather with drinking water is supposed by Hindus to defile it. Every imaginable kind of filth is thrown into running water in open channels which they use, and drink from, without hesitation; but as a pipe supply of water is itself an innovation, it is better to humour such prejudices than to risk the consequences of fighting them. Prejudice and even hostility may arise in the most unexpected manner. The stand pipes of Allahabad were decorated with the well-known device of a lion's head, from which the water issued. Complaints were made that a dog's head had been introduced into the pattern of the stand pipes, which was offensive to Hindus.

On hearing of this, certain members of the Cawnpore Municipality stipulated that this dog's head should not be used in the stand pipes about to be placed in their town. By some misunderstanding a certain number of the offending pattern were brought to the town, the pattern having in the meantime been accepted at Benares, a town famous for the strength of its religious opinions.

The Cawnpore Municipality at once held a meeting, at which it was decided to use the "dog" pattern in the European and Mahomedan quarters, and to have a horse's head in the Hindu quarters of the town. It did not seem to have occurred to any one to abolish the head altogether, as a mere ornament which was not necessary in the design of a stand pipe.

There is to be seen, in the Victoria Gardens of Bombay, a very graceful pattern of a stand pipe in cast-iron, from which drinking water issues through the calyx of a flower. The idea is singularly appropriate in a land where a taste for flower decorations is universal.

Waste of water means not only unnecessary expense, but the frequent wetting of many unpaved surfaces of ground, more or less saturated with organic filth, which, when dry, are much less offensive.

The impurities existing in the water supply of Indian towns vary according to the source from which it is taken. Storage reservoirs have their special impurities, mostly of a vegetable origin.

In collecting reservoirs weeds grow at the bottom, in depths variously estimated at from 12 to 16 feet. The limit of depth appears to be principally regulated by the penetration of light through the water. The bottom temperature, which, in deep reservoirs, is much lower than that of the surface, has also a limiting influence in vegetation below.

The most troublesome surface weed is a small green plant which grows with extraordinary rapidity in still water, and has the appearance of a fine irregular network, which extends at times to six feet below the surface. It is known to botanists as the *Wolffia Delitii*, and it grows during the whole of the year. During the prevalence of winds, it will drift to the lee side of the reservoir in close masses and decompose, giving off a smell which resembles that of nightsoil.

The continuous growth of this plant involves continuous decay and a continuous descent of the dead plant through the water. Its specific gravity, when living, must be very nearly that of the water in which it is suspended, and the loss of the air, by means of which living plants float, will cause its descent.

The dead plants form a layer of mud at the bottom of the reservoir, which contaminates the water to some distance above it, and this mud, according to observations made at the Vehar Reservoir of the Bombay Water Works, accumulates and limits the depth at which pure water may be drawn off. It is easy to foresee that the capacity of supply of any reservoir may be limited not only from reduction of surface level, but from contamination which rises from the bottom. This has already been observed in the Bombay Water Works, and it suggests the desirability of having means of drawing off the bottom water from time to time, so that accumulations of deposit may not lie in the vicinity of the draw off valves.

The annual monsoon supply has little or no effect on the bottom water of a reservoir; the fresh rain water, being warmer, and consequently lighter, than that of the lake, floats upon it as river water does on the ocean. The dead weed does not lie in a hard layer at the bottom, but is rather in a state of suspension, more or less close, for many feet from the bottom.

As this source of contamination is quite independent of all others, such as that due to neighbouring pastures, cultivation, villages, or any of the ordinary sources of impurity which may be found on a catchment area, it demands separate consideration.

In Major Tulloch's Report on the Water supply of Bombay, there is an Appendix containing a memorandum by Dr. Blaney on the state of the water in Vehar Lake during the month of May; the month preceding the monsoon. In this memorandum the lowest safe level at which water might be drawn off for the supply of the city is discussed.

In May 1865 the water level in the reservoir reached a minimum of 44 feet at the tower gauge. The supply was then discoloured, thick, with vegetable matter, and offensive to taste and smell. The deaths registered in that month were 3,792, or about 100 per cent. above the average. The deaths in the month of May from 1865 to 1870, inclusive, were as follows:—

TABLE IX.

Years.	Total deaths.	Water level at close of dry season.		Water level at the commencement of the previous season.	
		ft.	ins.	ft.	ins.
1865	3,792	44	0	55	9
1866	1,735	46	1	57	4
1867	1,448	46	2	59	0
1868	1,452	47	6	57	0
1869	1,737	...		...	
1870	1,241	...		...	

In the absence of any water analysis for the period under review, it may be remarked that differences of 2′ 1″

and 2′ 2″ of level above that of 1865 indicate that the zone of dangerous impurity must be very clearly defined, and that the water lying below the line of dangerous impurity should, as far as possible, be got rid of or purified. The weed in question was supposed at the time of Major Tulloch's Report to disappear from the surface under the influence of the first monsoon rains, but recent inquiries refute this idea. It is found in all the tanks of Bombay, and contributes largely in rendering their waters unwholesome.

The water in the mains has, at times, suffered from the contamination of dead fish, which have been found as long as 4 feet, with a girth of 12 inches, within the pipes. Their appearance in the pipes is attributed to the temporary removal, or perforation from decay, of the strainers in front of the take off valves. There is no evidence to prove that fish will live and grow in water mains for any length of time. Fish in underground rivers traversing caverns lose their colour and their sight. The absence of facilities for breathing in a pipe filled with water would probably prevent any fish from living long in it.

The objections against any one weed in a reservoir of potable water apply to nearly all weeds. While they are living they absorb impurities, and when they are dead they rot and foul the water.

The *Wolffia Delitii* does not appear in rivers, as it seems to require still water to grow in, but rivers in India have many sources of pollution which reduce, although they do not destroy, their value as potable water.

If navigable, they receive the whole of the sewage of the boating population, and as much of the sewage from the towns and villages they pass as will flow in. Dyeing, tanning, or other works are carried on the banks, and their refuse is thrown into the river. Dead bodies, partially burnt and unburnt, are disposed of in the river, whatever the disease that killed them, and regardless of the volume of the river, which at certain seasons may be no longer navigable for produce boats.

When the rains begin, the surface filth of the whole water shed is carried into them along with enormous masses of fine sand and earth, which finally assist to build up deltas at their mouths. The same remarks apply in a modified sense to canal waters, which, however, have no industries established on their banks.

In spite of all these sources of impurity, water works stationed on large Indian rivers have amply justified their existence by the reduction of mortality that has followed their establishment. This may be taken to prove that the water was better than that of sources previously used by the town.

The processes by which the water is prepared for use are limited in India almost entirely to precipitation in settling tanks and filtering through sand. The Revolving Purifier is used at Agra Water Works, in which the water is brought into contact with iron borings and with finely divided air which is blown through it. It is a moot point whether the improvement in the purity of the water is due to the oxide of iron or to the aëration.

The settling tank and the sand filter may be regarded as mechanical filters, although the amount of albumenoid ammonia is actually reduced, to a slight degree, by sand filtering.

Indian rivers are decreasing in volume in the dry season in proportion to the amount of water drawn off for the purposes of irrigation, and, as the population along their course is increasing, the proportion of impurities they contain may be expected to increase. Sources of water supply have been rejected for small differences of probable impurity, although other circumstances, such as cost of construction and maintenance, were much in their favour.

Considering the possibilities of pollution of all supplies of potable water taken from the surface in India, it seems that something more effective than the settling tank and sand filter are needed to insure the requisite amount of purity, *at all times*, of drinking water. An unusually severe visitation of cholera in a townor district, a few miles above a water works pumping station, might have consequences that are very unpleasant to contemplate. Cholera corpses are thrown unburnt into rivers in spite of every precaution the authorities may take to prevent the habit. They are there torn to pieces by birds or by crocodiles, while the contents of the intestines mingle with the water which is to be used for drinking lower down the river. All surface waters in India may be regarded as polluted with sewage in some degree, and as requiring a preparation for use somewhat analogous to that employed in England for the purification of sewage that cannot be got rid of by irrigation. The "International" process of sewage purification may be cited as an example. Here precipitation in the settling tanks is accelerated by a solution of "ferozone," and the sewage water, after depositing its solid matter, is passed through a layer of six inches of "polarite" prepared from magnetic iron ore, and placed in a filter. The apparatus is of the same class as that used at present in water works, and as the consumption of the purifying material will not be in proportion to the volume of water treated, but rather to that of the impurities it might contain, the cost should be very much less than that of purifying sewage. Further, the rate of work of a chemical filter is so much more rapid than that of a mechanical filter of a given area, that a much smaller area of filters might be found sufficient for the works.

CHAPTER IV.

HOUSE DRAINAGE.

The best means of removing organic refuse of all kinds from dwellings in India is a problem that has not yet received its solution.

What might be called the natural method, which consists in throwing everything out of the house by the doors or the windows, has the distinction of high antiquity, and its popularity is great even at the present time, in spite of its close relationship to a high rate of mortality. A custom which is as old as inhabited dwellings—as old as cooking—goes a long way back in the world's history, and is not to be easily shaken or superseded by the very best of modern science.

The human factor, in the general sanitary problem, which might be called x, on account of its unknown quantity, stands above every work of the sanitary engineer as the arbiter of its success or failure, and there is no appeal against its verdict.

The history of sanitary experiments on a large scale in India has already furnished several striking instances of schemes, "that ought to have worked but wouldn't," and in each case it has turned out that something, or several things, had been taken for granted without any warranty whatever, and as there was really no equation, the problem would not solve.

The case stands thus:—

Given, a people whose taste and immemorial habit is to throw all house-refuse out of the doors and windows, and to make a latrine of the street. This is not a picture of the Indian people alone, but of all primitive people. What is the best alternative you can offer them, and what inducement can you give them, in addition, to use it?

We are already out of the domain of strict engineering, and entered on something very like a diplomatic career!

But there is no help for it; we are really attacking social customs, and must justify our actions; and this is exactly where the great difficulty arises. The rate of mortality is not to be reduced in a week, and if it were, it would be a change of custom.

Fortunately there is such a thing as social progress, even in India. The opposition is really not entirely against sanitary reforms, but largely against the cost of it, and the objection to cost in relation to revenue is one that was never more important than at the present time.

The question before us is, the removal of house-refuse from the building to the drain or sewer, in the cheapest, quickest, and most efficient manner. The refuse consists of bath-water, cooking-water, and water from the washing of utensils, vegetable refuse, sand and earth used for cleaning utensils, the sweepings of floors, straw, rags, paper, leaves, broken crockery, and dead vermin; everything, in fact, that is not wanted and can be pushed into the outlet hole of the *nahni* or sink, which is usually built in the floor. Urine is regularly discharged into it at nights, and children use it as a latrine. We will take, for instance, a house of three stories, that is to say, with two floors in addition to the ground floor.

Anything that cannot be pushed into the outlet hole of the '*nahni*' is thrown out by the door or the window.

During the day the windows are all open, but at night, especially during cold or wet weather, the shutters are closed, and, as every room is a sleeping as well as a living room, the ventilation is in part through the *nahni* pipe, the lowest opening in the room. The room when inhabited and closed up becomes several degrees warmer than the outer air, and must be regarded as a chimney with an upward draught. The warm air of the room will escape by any opening near the roof, or at the upper part of doors and windows, and air from without must replace it. In this manner, the *nahni* and any open pipes connected with it become a source of air-supply to the room.

In 1890 the author made an experiment on the down-take pipes of a house in Bombay, which had been fitted up without wall syphons. The house was of three stories. The observations were made at about 3-0 P.M.; the side of the house against which the pipes were fixed was in the sun, and a faint breeze blew against it, producing a slight current through the house. The down-take pipe was common to the two upper stories, and discharged into a horizontal pipe fixed to the wall, which led towards the sewer. Twelve or fourteen feet away from the down-take pipe was a short upright branch on the horizontal pipe, not in use. A roll of smoking brown paper was held to this opening; the smoke was at once drawn down the branch, along the horizontal pipe and up the down-take, from whence it passed through the *nahni* into the house. This was while the windows were all open.

At night the heat of the wall would keep the down-take pipe warmer than the outer air, making a chimney of it to assist the indraught of the room. The tenants in the house were all more or less sick, and they complained that since the pipes were fixed they were scarcely ever well. The cause of nuisance in this case is perfectly clear. The putrid lining of the down-take pipes discharged the foul gases of which the people complained, and until this gas could be led elsewhere than into the house, sickness would continue. This fouling of the down-take pipes seems to be one of the inevitable results of the temperature of the air, and can only be remedied by proper ventilation.

In Bombay it has been for long the custom to use earthenware pipes embedded in good mortar to take the drainage down the side of the house from the upper floors. It was cheap, and the materials were produced locally. In the interior of the country, as at Lucknow, Cawnpore, Allahabad, and elsewhere, a vertical groove in the masonry of the wall forms an open conduit for the passage of liquid-refuse to the ground. The same is to be seen in Baroda and Ahmedabad. At times this groove is roughly covered with the tin of old kerosine cases, so as to form a rough pipe, and prevent splashing of the liquid. This method, although very simple, saturates the wall in time, with putrescible matter, which decomposes out of contact with the sun and air, and renders the house in its vicinity unwholesome.

During the past 14 years, a large portion of Bombay has been fitted with cast-iron down-take pipes and syphons of English pattern to carry liquids from storied houses by a vertical pipe common to several stories, and convey it to a house drain leading to the sewer. This system had been thoroughly tried in England, and was confidently introduced in Bombay as that best suited to the needs of the town. After 14 years of trial, during which everything was done to facilitate the working of the pipes, a Committee was appointed to enquire into the working of the house connections, and to deliberate on possible improvements. Almost all the witnesses who were examined condemned the syphon seals as unsuited to the habits of the people who used them.

Being designed to carry liquids alone, they had been loaded continually with sand, earth, rags, and any other solid waste matter that could be got into them. Owing to the high mean temperature of the climate, not to speak of the maximum temperature, the pipes remained 24 degrees above the temperature at which putrefaction begins, and soon acquired a very foul lining of organic matter which attacked the metal of the pipes, and which discharged the gases that sewage gives off when decomposing in the dark.

Here were two new elements that did not appear in the same arrangements in England: the constant choking of the syphons causing overflow, and the rapid formation of the putrid lining in the pipes.

Ventilators were made by extending the down-take pipes upwards to several feet above the roof: these ventilators worked well when the pipes were empty, and warmed by the sun, but when colder than the air, which would happen every day soon after sunrise, the current was downwards. The mixed gases of putrefaction are, at equal temperatures, heavier than atmospheric air.

When water was thrown into the down-take pipe from any of the *nahnis*, it drove before it the foul air in the down-take pipe to the nearest outlet at each storey on its descent, and drew behind it fresh air through the nearest inlet to replace what was driven out. This foul gas was liable to pass in at the nearest window, and as it was *very* foul, it frequently gave rise to complaints and to sickness; the solid matter, which the Bombay Municipality was powerless to prevent being put into the pipes, lodged in syphons and gully traps, and made it perfectly plain that unless both syphons and traps could be made to pass all the solid matter which got into them, they were unsuited to the requirements of Bombay people.

In order to make wall syphons self-cleansing, a current with a velocity of at least three feet per second is required, plus an additional velocity to lift the solid matter over the end of the syphon. This added velocity would be that at which the matter would fall through still water of the depth of the lift over the end of the syphon.

The difficulty is aggravated by a disposition of the organic matter to form a cake of the sand if left for a short time.

After caking has taken place, no current that would be put through from the *nahni* would move it.

The following may be taken as the approximate rates at which various substances fall through still water, according to experiments made by the author:—

Coarse sand	0·94	feet per second.
Gravel	1·00	,, ,,
Scraps of pottery and brick...	1·25	,, ,,
1-in. stones of blue trap-rock...	2·50	,, ,,
Scraps of iron, 1½ inches long.	3·10	,, ,,

Animal and vegetable substances being all lighter than the above list, would pass in a current that would carry stones. Taking blue trap as the basis of calculation, with a falling rate of 2·50 feet per second, the velocity of current through a syphon when solid matter is passing should never be less than 3 feet, plus 2·50 feet, or 5·50 feet in all.

In a 2½-inch down-take pipe this would amount to a flow of water equal to 70 gallons per minute.

There is, however, no fixed ratio in the proportion of solids to liquid thrown into *nahnis*, and it frequently happens that the amount of water is only sufficient to carry the solids into the syphon and leave them there. People who have to carry water from stand-pipes into storied buildings will not dispose of it for flushing purposes, which to them would appear to be sheer waste.

If the size of the pipe be increased, the velocity of current through the syphon would have to be kept up by an increased flow of water. In a 4-inch pipe water must flow at the rate of 178 gallons per minute, and in a 6-inch pipe at the rate of 402 gallons per minute. Setting all calculations aside, the experience of fourteen years has proved that a syphon on a tenement house in India is simply a trap to catch solid matter and block the down-take pipes. With respect to the diameter of down-take pipes for storied tenement houses, 2½ inches appears to be large enough when not obstructed by syphons or elbows in which materials might lodge, its power of discharge being greater than the rate at which water could be put into it from *nahnis*, but if this (minimum) size be used, a good grating should be securely fixed in the *nahni*, so that no solid matter large enough to block the pipe may pass in. The grating should have holes of a fixed *length* and *breadth*, and their total area should be equal to that of the pipe. The pipe below the grating will thus require to be enlarged in the form of a funnel to receive the grating.

The pipe must have a clear passage through it from every *nahni* to the outlet at the foot, and with such a fall between the grating and down-take that nothing will lodge and remain in it.

The fouling of the interior cannot be arrested, being due to climatic conditions; it therefore requires ventilating in such a manner as shall deliver the foul air above the roof of the house, and not into the narrow gully which separates houses from each other in Bombay, and which supplies air to the rooms. There must also be a means of preventing the air from being driven by the discharge of water from one house into the next one below it, or into several houses. This would follow if no means existed for closing the *nahni* pipes when not in use. Self-acting valves for such a purpose are so difficult to construct, that no one has yet succeeded in producing one that would wear well and keep in order under the conditions existing in Bombay.

The Turks and Arabs, whose *nahnis* all discharge into cess-pits, have a device which, although not self-acting, is so simple that it has stood the test of many generations. It is a small slab of marble which lies over the outlet hole in the marble floor of the *nahni*, and is slid off and on by a push from the hand or foot, as occasion may require. The slab must fit the surface at the outlet hole, and once in place both smells and vermin are excluded.

The down-take pipe must also have a valve, or its equivalent, at the foot, to arrest the escape of the air driven downward by descending sullage, and yet to allow the escape of the water and the solid matter that may accompany it. A catch-pit into which the down-take pipe dips is the simplest form of seal, the depth of "dip" being regulated to resist the pressure of the descending air. This catch-pit, if made rectangular, with one side sloping at an angle of 60° with the horizon, and with the down-take pipe at the opposite side to the slope, may be easily cleaned by a single stroke of a rake or scraper made of the width of the pit, and drawn along the bottom and up the sloping side.

The fault of this catch-pit is that the seal of the down-take pipe is reduced by the volume of solid matter withdrawn, and if neglected for too long, the cleaning out might unseal the pipe altogether until the catch-pit was refilled with sullage. The risks of possible, nay probable, neglect, must be weighed against the advantages of any system, bearing in mind always that perfection under the circumstances is not only impossible, but absurd.

If the catch-pit is inadmissible, a valve must be used to close the foot of the pipe against the escape of foul air, but this must be regarded only as a last resource, as moving mechanism rarely works well in contact with sewage. Valves as a rule require either one or more hinges, or their equivalents, which in time will rust and stick fast either open or shut. Air valves are besides very difficult to make and maintain in good order, and it is an *air* and not a *sewage* retaining valve which is needed. On the other hand, the pressure of air against which it has to work is exceedingly low, and if the leakage is not excessive, and it works without sticking or fouling, it may be considered a good working device.

The valve, Figs. 1 and 2 on Plate III., has been designed for closing the foot of a down-take pipe. It is too new to speak of its merits, and only a considerable period of trial can decide as to its suitability.

Plate III.

Self acting Valve
for the foot of a
Down-take
Sullage Pipe.

Fig. 1

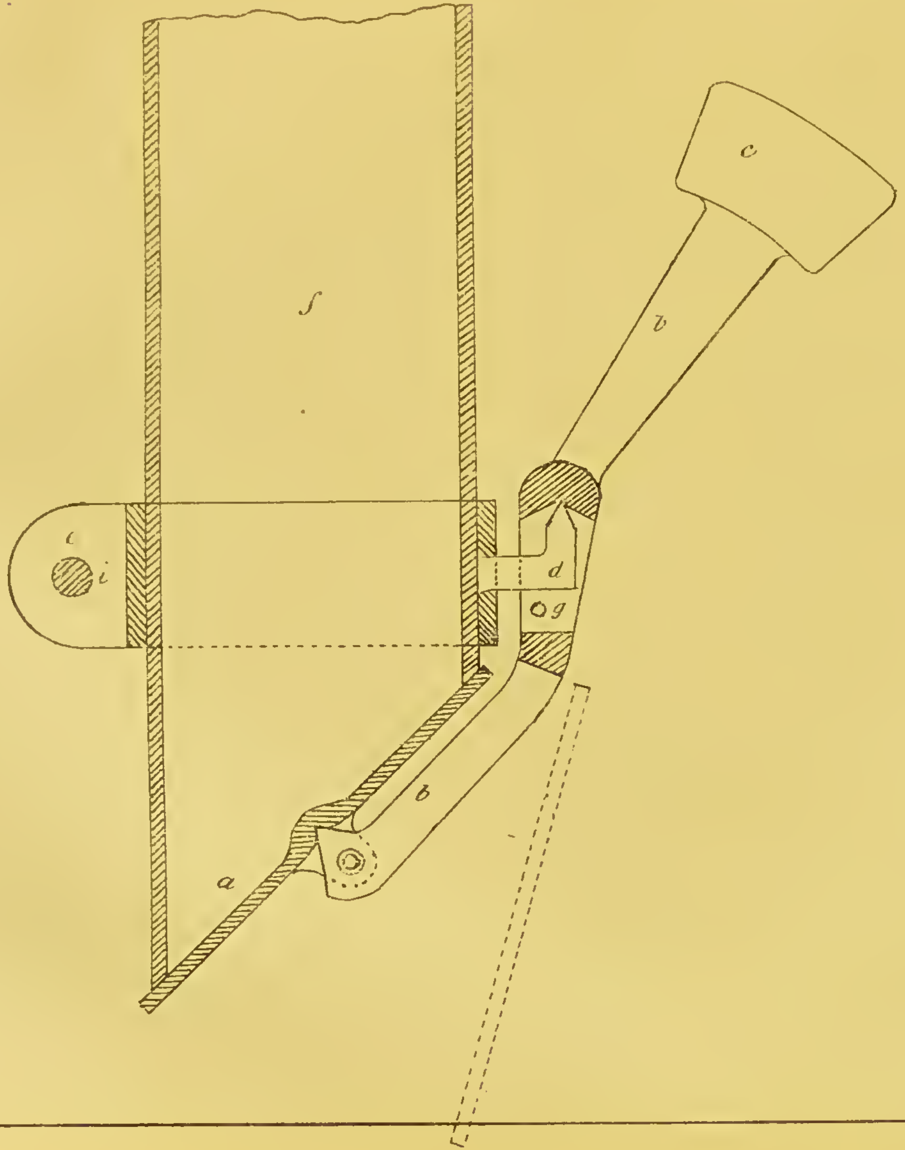
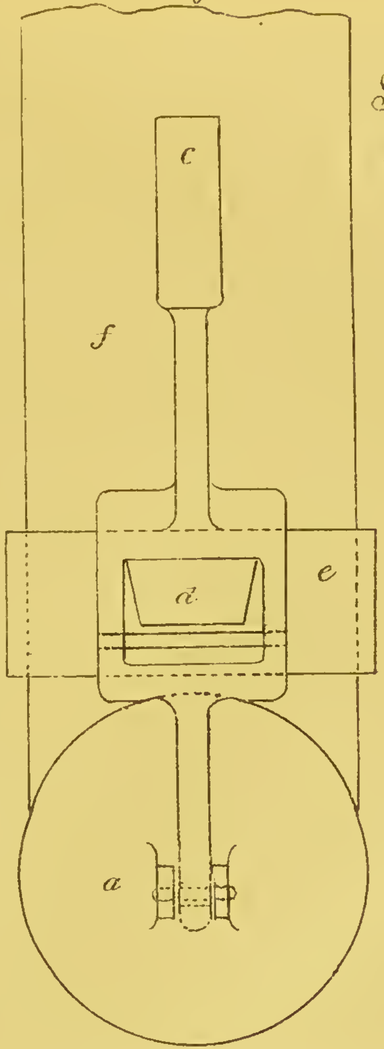


Fig. 2



The following description will explain its details and mode of action:—

The down-take pipe F is cut at the foot to an angle of 45°, and the valve *a* is held against the mouth of the pipe by the point of a lever *b*, which presses on a recess in its centre. The lever *b* hangs on the edge of the bracket *d*, and has at its end the balance-weight *c*, to close the valve. The bracket *d* forms part of a collar *e*, which clasps the down-take pipe, and is held tight by a bolt *i* passing through lugs on the collar or hoop *e*. The lever is enlarged to receive the bracket *d*, and the edge on which it hangs is protected from dirt or injury by the overhanging sides of the lever. The pin *g* prevents the lever from being removed, and at the same time allows of free movement. Lugs project at the back of the valve *a* to receive a pin which passes through a wide hole in the end of the lever, and forms a loose but secure attachment.

The valve may be of zinc, white metal, or of cast-iron, enamelled on its inner face. The balance-weight *c* is adjusted to resist the pressure of air coming down the pipe and to open for the passage of water and solid matter.

The escape of the air may be provided for by a parallel return pipe connected at each storey with the down-take pipe. The ventilating pipe is continued to a sufficient height above the roof to avoid the risks of down-draught, and the down-take pipe terminates at the upper end, on a level with the highest floor, with a capped opening. Through this opening, which will be accessible from the nearest window, a weighted tube brush may be lowered by means of a cord to clean the interior of the down-take pipe. During this operation the pipe should be flushed from the upper floor to carry down the sweepings.

In many cases a weighted-pipe scraper, of the pattern already used for cleaning water-pipes when coated with internal deposit, might be used with advantage. One insertion would be sufficient. A metallic scraper has one drawback which should be noted. If the pipe has been tarred within, it is likely to remove the tar in places. Hard wood might be used in some cases for the scraper points.

CHAPTER V.

SURFACE AND UNDERGROUND SEWERS

Sewage is a term that may logically be made to include all the refuse-matter, solid, liquid, and gaseous, that is produced by communities of human beings. The original definition, *i.e.*, that which is carried away by sewers, no longer applies, as sewage is carted in enormous quantities, but going to the root, *essuyer*, to make clean, sewage becomes *that matter which is removed to produce cleanliness*, and thus includes the three forms above indicated.

It is the organic matter in sewage which gives all the trouble, and which provides the *raison d'être* of the Sanitary Engineer.

The decomposition of sewage is a subject upon which chemists are not yet in agreement, and which does not properly belong to this work ; it will be sufficient for the present purpose to say that the organic parts, of animal or vegetable origin, in contact with water, decompose in a manner that is greatly modified by the action of air, light, and heat, and produce gases and other emanations, such as bacteria and loose particles, that are injurious to the human system if respired or otherwise absorbed into the body.

If sewage be confined in a dark chamber with a very limited supply of air, it decomposes and discharges compound gases, such as —

Sulphuretted Hydrogen.
Carburetted Hydrogen.
Carbonic Acid.
Hydrosulphuret of Ammonia.

All these gases are injurious to health, and all are fatal if inhaled in excessive quantities. Although pure Carbonic Acid gas has no odour, it never escapes pure from sewage, but is always mixed more or less with some of the others. There is, therefore, no such thing as the escape of poisonous gases from sewage that do not stink.

Sulphuretted Hydrogen, recognisable in the smell of rotten eggs, is dangerous to human life when existing to the amount of 3 per cent. in the air, and horses and dogs are affected by an admixture of from 0·13 to 0·40 per cent.

Carburetted Hydrogen and Olefiant Gas produce poisonous symptoms when present to the extent of 20 to 30 per cent., according to the resisting power of the individual. These gases are also explosive when mixed with their combining proportion of atmospheric air *and ignited*. Carbonic Acid has produced poisonous symptoms in man when present to the amount of 5 per cent., and 1 per cent. is fatal to many of the lower animals.

Dr. Angus Smith, in order to determine practically the influence of Carbonic Acid on the human system, constructed an air-tight chamber, in which he sat while lamps consumed the oxygen of the air and produced 3·84 per cent. of Carbonic Acid. He experienced rush of blood to the head, a feverish activity of mind, and his respiration rose to 26 per minute from a normal of 20.

If fresh sewage is exposed in a thin layer to the sun in a current of dry air, it becomes rapidly innocuous without the production of several of the more offensive gases. This method of treatment is, however, practically impossible on any large scale.

Admixture with loamy soil is the most perfect method of deodorising sewage, either solid or liquid, but it is only practicable on a limited scale, and in small communities. Dilution with water, so as to make it flow in channels, covered or open, to the nearest river, has in Europe been the favourite means of sewage disposal, but in India this method is not always practicable for several reasons.

Most of Indian rivers, if not dry during a part of the year, are greatly reduced in volume, and none of them have, up to the present time, received the whole discharge of the sewage from any large town. None of the inland towns are as yet properly sewered, and the amount of sewage they deliver into their respective rivers is only a very small fraction of the whole product of the town. Satisfactory experiments have been made on the rate at which small volumes of sewage disappear in the Ganges and the Goomti during the dry season, but no reliable data can be obtained from such experiments regarding the effect of twenty or forty times the quantity of sewage discharged at one point into the same rivers at the time of their smallest volume.

There are also difficulties, still unsolved, regarding the outfall or junction of the main sewer with the river, which experiment alone can decide. The sewage must be delivered well into the stream during the period of smallest volume of the river, so that it may be thoroughly diluted, but, as the level of the river may vary twenty or more feet vertically, the low-water discharge would, owing to the silt carried by the river during floods, be probably blocked at every rise of the river. A stoppage of discharge might be avoided by having several outlets to suit various states of flood, and digging them out at least once a year, if silting proved to be troublesome.

Such difficulties of outfall are not, however, sufficient of themselves to condemn a sewage scheme. Communication with the river at the Agra Water-works is maintained, at low-water, by digging a channel from the stream across the river-bed to the intake of the pumps.

The respective merits of surface and underground channels for the transport of sewage away from a town have been much debated in India, and the discussion has not always been carried on in the manner best calculated to lead to a satisfactory issue.

Both belong to the water-carriage system of removal, and each must have a certain quantity of water to carry its contents. Both, for purposes of comparison, must have properly-built channels, with suitable grades to give the liquid its proper velocity of flow, and both must be kept clean, so that accumulations of putrescible matter may not form in their beds and create a nuisance.

It must be evident to the advocates of both systems that in the streets of most towns an open main sewer would be objectionable for the space it would take out of the roadway, and if it happened to be deep, its cost, built open, would be greater than that of an underground sewer. There are only three towne in India which possess well-built underground sewers. Of these, Bombay and Calcutta are the chief examples, and in each the English system of connecting the houses by means of pipes, syphons, and gully-traps has been tried with anything but encouraging results.

The question, reduced to practical form, is not so much whether the *whole* of the channels for the removal of sewage and sullage should be open or closed, but is rather one of the distance to which the sullage and such waste organic matter (excluding excrementary matter) may safely flow in open channels before passing into underground sewers.

In the "Sanitation of Bombay," by Mr. Baldwin Latham, the following passage occurs:—

"The temperature of the sewage of Bombay at the "present time is likely to be considerably augmented by "reason of the pernicious system of permitting it to be "exposed in open channels to the sun's rays before it is "admitted into the underground sewer, which exposure "increases the liability to decomposition of the sewage "and renders the sewage very offensive when it reaches "the sewers. No time should be lost in at once abolish-"ing all open channels for sewage and conveying the "whole of the sewage by proper drains to the sewer, for "it must not be forgotten that sewage is a dangerous "article to play with in a hot country, the inhabitants "of which are susceptible to a variety of intestinal and "other disorders capable of being transmitted by "sewage."

The above, as the opinion of a distinguished Sanitary Engineer of wide experience in Europe, is entitled to be read with attention. It is perfectly true *for England*, but the experience of 14 years in Bombay has shewn that the necessary fittings that must interpose between the house and the sewer could not be kept in order on account of the solid matter thrown daily into them. The result was an overflow of sullage and an increase of the danger and nuisance that the pipes were intended to prevent. Down-take sullage pipes have also been largely tried without syphons; they at once became conduits for sewage gas into the dwellings, and sickness was in consequence increased.

The efficiency of the arrangement recommended by Mr. Latham, and which has given satisfaction in England, depends largely on the co-operation of the people whose habits it suited. The same co-operation is not to be had in Bombay, or in any town or city in India, therefore the house drain and the wall syphons failed. It is true that exposure to the sun in shallow channels will raise the temperature of sewage, but the *period* of exposure must be taken into consideration.

In the narrow passages known as house gullies, that divide the large tenement houses of Bombay, the sun can only shine for a very short period of the day, and even in the streets, the great majority of which are narrow, the time during which the whole width of the street is illuminated, unless it lies due East and West, may be counted in minutes.

Still-water in a shallow layer of four inches, with an earthen bottom, has been known to acquire from the sun in Bombay a temperature of 91 degrees, after an exposure of five hours. The same result might be expected from sewage exposed in stagnant gutters, for the same period, but in a town with an adequate water-supply—and this is an absolute necessity in a town which would remove its sewage by water carriage,—the grade of the gutter, and the amount of flushing it can get, may be regulated, so as to carry the sullage within any required time from the house to the sewer. Flowing at the rate of only 1½ feet per second, it would travel 90 feet per minute, or 450 feet in 5 minutes, and if the flow were continuous, the temperature of the gutter would be considerably below that of the neighbouring dry ground.

A case may be taken from Cawnpore, which has a much greater range of temperature than Bombay.

Cawnpore obtains its water for drinking and for watering the streets from wells distributed about the town. The water in the hot season has a temperature of 82° when taken from the wells, and the river Ganges, into which the sewers discharge, has in the month of May a temperature of 81°. The wells average from 35 to 50 feet in depth, and the temperature of the ground at the depth an underground sewer would be laid would not be less than 83°.

The population in 1891 was 182,000, and all the sewers are uncovered.

Most of the sewers and street gutters are as bad as it is possible to be, being badly built, badly graded, and inadequately flushed. As a natural result, the rate of mortality, according to the report of the Sanitary Commission, averaged 54 per thousand for ten years prior to 1890.

The Sadar Bazaar in Cawnpore deserves special notice on account of its present condition. It lies between the City and the Cantonment, and is without any outfall for its sewage. Until the year 1889 it was within Cantonment boundaries, and its sullage, containing a great deal of sewage, passed away by an open drain going through the Cantonment Bazaar. When in 1889 it was taken over by the Municipality, the Military authorities promptly closed their drain, and the Sadar Bazaar, lying as it did between the Cantonment and the Ganges Canal, was at once without an outlet, for sullage is rigorously excluded from the canal.

The gutters of the streets in this bazaar are on each side, close to the houses and shops; they are irregularly graded. Two pits have been constructed to receive their contents, which are removed by tank carts. At times these pits overflow, and hundreds of feet of gutters are filled to a width of from one to five feet with a black, foul-smelling liquid, which saturates the soil and contaminates the wells. The wells for the most part are not properly protected from surface water.

The removal of sewage and mixed sullage is effected by carts, which remove daily 45 loads of liquid from the gutters, and 22 loads of fæces. A load consists of 11·2 cubic feet or 700 lbs. By comparing the amount of liquid carted away with the average amount drawn from the wells or the canal, the quantity absorbed by the ground may be ascertained. Seven gallons and a half per day per head for 18,000 persons amounts to 135,000 gallons or 1,800 loads. Deducting 45 loads from 1,800, we have 1,755 loads or 126,000 gallons of fouled water, which, thrown from the houses into the streets, saturates them with organic filth, and leaks into many of the wells.

The excrementary matter from 18,000 persons in India amounts to eight ounces of solid and two pounds of liquid per person, or 45,000 lbs. per day. This is equal to 64 loads of 700 lbs. Deducting the 22 loads which are carted away, there remains a quantity of 42 loads, which, mostly urine, contributes to the saturation and fouling of the ground. When the monsoon arrives, the bazaar is flooded, and overflows into the canal and the Cantonment, getting rid of much of its surface filth; but the washing penetrates only a short distance below the surface, and in the intervals of rain a tropical sun heats the wet ground and sets up an active decomposition of the organic matter it contains. In the cold season the low temperature of the nights brings down much of the vapour that the atmosphere contained during the day, producing fogs which lie on the ground from sunset till sunrise, and arrest and absorb the gases of putrefaction that escape at the time of low barometric pressure in the early morning; these fogs are always accompanied by an increase of the death-rate.

The death-rate in Sadar Bazaar for six months between April and September of the year 1892 was 64·66 per annum, or 10·66 in excess of the mean of 10 years for the city.

Health Officers are only too familiar with the conditions just described, but in justice to Cawnpore it is fair to add that in the scheme of drainage projected by Mr. A. J. Hughes, the Supervising Engineer of Municipal Works in the N. W. Provinces, Sadar Bazaar will be the first section of the town to have its drainage and water supply completed.

Along with some of the worst examples of open sewers in India, Cawnpore possesses a few open street gutters, so well laid and kept as to afford valuable data on the question referred to on page 88 of the safe distance to which such sullage as comes from Indian houses may run in an uncovered drain.

Gilles Bazaar is a street lying due North and South. It has brick-lined shallow "saucer" gutters on each side, into which the house drains discharge. The house drains are sometimes open and sometimes covered; they have all been made by the builders of the houses, and are in many cases neither smooth nor well graded. The street gutters are laid with a fall of one in one hundred, and are each 950 feet long.

The population in this street on each side averages 475, and the consumption of water per head being 7·5 gallons, plus 45 gallons used by the sweepers during the daily sweeping of the gutters, the total amount of water discharged into these gutters per head is 7·6 gallons.

Owing to the defective laying of the house drains or gutters, especially of those that are covered, solid matters frequently remain too long in them and putrefy.

Nevertheless, with 7·6 gallons of water per head per day, and one visit of the sweepers, the 950 feet of open gutter are kept in excellent order, and the street is remarkable among the various streets of Cawnpore for its freedom from smells. The maximum temperature of the air at the time of observation was: Day, 103°; Night, 90°. Humidity, 25 per cent. (day).

A reduction of the number of connections between houses and the street sewer has so many advantages, both in point of first cost and of maintenance, that if the proper length of open gutters had to be determined experimentally for every separate town in India, it should still be done.

The first cost for direct connections in towns in the interior is Rs. 70; their life has been found in Bombay to be 10 years, and their maintenance charges, owing to their liability to blocking, are very heavy. If a syphon remains for a few days unused, it becomes unsealed by evaporation, and, if in an empty house, it may remain for a long time without attention. The high temperature of the ground, and the dryness of the air, produce a much higher rate of evaporation than is known in Europe. On the other hand, if one syphon serves to connect several houses with the sewer, the chances of its becoming dry are greatly reduced, and there is only one catch-pit to attend to on the sewer instead of several.

Ventilation of Sewers.

The influences which chiefly affect the movement and the quality of the atmosphere of sewers are:—

The rate of decomposition due to temperature.

The alteration of volume of liquids in the sewer due to the varying use of water during the day.

The alteration of volume due to the influx of storm water.

The fluctuation of barometric pressure.

The influence of winds on the outfall.

The discharge of steam and hot water from boilers when blowing off, and the discharge of air from dust or ventilating fans in factories.

This subject has had careful attention in England. In Parkes' " Practical Hygiene," p. 108, it is stated that in twenty-three observations on a Liverpool sewer, it was found by Drs. Parkes and Burdon Sanderson that in fifteen cases the pressure of the air in the sewer was less than in the atmosphere outside (*i.e.*, the outside air had a tendency to pass in), and in eight cases the reverse; but on the average of the whole there was a slight indraught into the sewer. In the London sewers, on the other hand, Sanderson noticed an excess of pressure within.

These data must be read in connection with the information of the same authorities on the composition of the air in the sewers of London and Liverpool.

In London the air of many sewers is not very impure; the analysis of Letheby and Miller have shewn that generally the amount of carbonic acid is very little in excess of that of the external air, and that there is hardly a trace of hydrogen sulphide or of fœtid organic effluvia. *The air of the house drains is often, in fact, more impure than that of the main sewers.*

A more recent enquiry conducted, into the health of sewer men in Liverpool, resulted in a report that they had good health. But while the temperature of these sewers is generally below 55°, that of sewers in India will range from 75·2 in Bombay to 83° in Cawnpore.

In spite of the great benefits which have resulted from the analysis of air in Europe, the subject has been almost entirely neglected in India, where the rapid rate of decomposition would render it of the greatest value. There are, therefore, no data on the composition of the atmosphere of sewers in India, although their air is exceedingly foul. Among the causes mentioned (p. 104) which influence the movement and quality of the atmosphere in Indian sewers, the rate of decomposition due to increased temperature has considerable importance, although its exact value has not yet been determined. The varying volume of flow of liquid, due to domestic routine, amounts to about to one-half the total supply in six hours. This may be ascertained by gauging.

The effect of the sudden influx of storm water can also be ascertained by gauging, noting also the time during which the volume of liquid continues to increase in the sewer.

The increase of sewer gas due to the effect of periodical falls of the barometer may be observed with a delicate syphon gauge, as also the increase of pressure due to winds blowing into the mouth of a sewer.

A syphon gauge used by the author consisted of two straight and parallel glass tubes 22 inches long, joined by a metallic box at one end and open at the other; they are fixed on a board 12 inches long by 3 inches wide, with about ¾ inch space below. The tubes are 1¼ inches apart from centre to centre. An Engineer's plotting scale 2 inches long, divided into $\frac{1}{50}$ inch, is screwed to a small block of wood that fits between the glass tubes, so that the scale may lie with each edge exactly above the centre of each tube and slide along from end to end. The board is hinged to another board by one end, so that by adjusting a wedge between the boards any desired incline may be given to the syphon, which is filled half full with water slightly coloured with red ink.

When the syphon is inclined to a grade of one inch in forty, each division on the scale is equal to $40 \times 50 = \frac{1}{2000}$ of an inch of water pressure.

Air at 82° weighs $\frac{1}{851}$ of its volume of water, so $\frac{1}{2000}$ inch in water pressure would equal a column of air $=$ ·0355 feet in height. The theoretical velocity of a current due to a head of air of this height would be $\sqrt{\cdot 0355} \times 8 = 1{\cdot}507$ feet per second, or rather more than one mile an hour. If Ether, with a Specific Gravity of ·716 be used, then one-fiftieth of an inch on the scale would indicate $2000 \div \cdot 716 = \frac{1}{2793}$ of an inch of water pressure, equivalent to a column of air ·0355 ft. $\times\ 2000 \div 2793 = \cdot 0254$ feet in height.

The theoretical velocity due to this head is $\sqrt{\cdot 0254} \times 8 = 1{\cdot}27$ feet per second or 0·86 mile an hour.

Water in the syphon will suffice in most of cases, as, for instance, when it is desired to ascertain the efficiency of sewer ventilators at times of sudden flood from rain or during the changes of volume of sewage due to domestic service.

The simplest adjustment of the angle of the syphon is effected by means of three tapered gauges made of $\frac{1}{2}$ inch hard wood, with tapers of $\frac{1}{40}$, $\frac{1}{20}$ and $\frac{1}{10}$. They should be about 10 inches long, and when laid on the syphon tube the latter may be raised until the upper side of the gauge is levelled with a spirit level. The readings with the scale divided into 50ths of an inch will be in 2000ths, 1000ths, or 500ths, respectively, with the several inclinations.

The following table has been prepared to facilitate observations and experiments with regard to the movement of air in sewers and ventilating pipes :—

TABLE X.

Shewing the Theoretical Velocity of Air Currents corresponding to Columns of Water from $\frac{1}{2000}$ of an inch to 1 *inch at* 82° *Fah.*

Water pressure in inches.	Velocity in feet per second.	Water pressure in inches.	Velocity in feet per second.
·0005	1·507	·060	6·488
·001	2·131	·070	17·816
·002	2·984	·080	19·048
·003	3·692	·090	20·200
·004	4·263	·100	21·446
·005	4·752	·200	30·368
·006	5·215	·300	36·896
·007	5·656	·400	42·608
·008	5·923	·500	47·632
·009	6·389	·600	52·176
·010	6·736	·700	56·360
·020	9·528	·800	60·256
·030	11·632	·900	63·912
·040	13·480	1·000	67·360
·050	15·072		

The velocities given in the above table do not take into account the friction of air on the interior surface of the pipe, in which it may be passing, and which varies with the length and diameter of the pipe. The loss of head due to friction may be calculated by the following rules, in which H = the head or difference of pressure at each end of the pipe in inches of water, C = the quantity of air in cubic feet per minute, L = the length of pipes in yards, and d = the diameter of the pipe in inches:—

$$L = (3{\cdot}7d)^5 \times H \div C^2,$$
$$d = (C^2 \times L \div H)^{\frac{1}{5}} \div 3{\cdot}7,$$
$$C = (H \times (3{\cdot}7d)^5 \div L)^{\frac{1}{2}},$$
$$H = C^2 \times L \div (3{\cdot}7d)^5.$$

In calculating the area of ventilators, it will suffice to ascertain which of the influences act most potently during fifteen minutes. Three hundred feet apart is the distance on main sewers recommended by Sir R. Rawlinson. If this distance is found convenient, the diameter of the ventilator pipe may be calculated on the displacement of air per minute in a length of three hundred feet of sewer.

The object of this ventilation is to keep the pressure of the sewer atmosphere as nearly equal as possible to that of the outer air, and thus avoid the escape of sewer gas through the seals. It has nothing to do with rendering the sewer air fit for respiration.

In 1874 the author found that the upward current in the drain pipe of a lavatory in Newcastle on Tyne rose at times to a pressure equal to 4¼ inches of water. The lavatory was on the top floor of a lofty building, built on the approach to the High Level Bridge. A syphon pipe with a 7-inch seal was fixed below the basin, and thus the escape of foul gas was stopped. The down take pipe was not ventilated.

Attempts have been made in Bombay to render the sewer air more respirable by means of double ventilator tubes, with their heads pointing different ways, so that for every volume of foul air that left, an equal volume of pure air might enter. The pipes are of rectangular section, and costly on account of their double passage, but the result did not justify the experiment. Introducing fresh air seemed only to promote decomposition, and, judging from the record of accidents extending over 11 years, the safety of the men who had to enter the sewers was in no way increased by them.

The quality of the sewage varies in different districts of Bombay, according to the prevailing style of diet used by the inhabitants. Hindus, whose diet is fish, rice, and vegetables, produce, in the refuse of cooked and uncooked fish, rice water, and other vegetable remains, an exceedingly foul smelling sewage; and the sewers of the quarters inhabited principally by them are said to be unusually foul. Fish, especially those of the gelatinous kind, decompose in India very rapidly. They are frequently tainted before the fishing boats reach land, while the firmer fleshed fish remain fresh.

The peculiarities of Indian sewers are so different from those of Europe or of America as to require special treatment, based upon special experience. Some idea of their condition may be obtained from published reports of the fatal accidents which have occurred in them from 1881 until 1892 in Bombay.

Eleven deaths took place from suffocation, and one death from an explosion of inflammable gas. Five explosions have been officially reported, one of which was said to have taken place after the men had left the sewer, and without the presence of a light. No known sewer gas will explode spontaneously; this explosion must, therefore, have been due to a light left by some workman upon the apparatus used for cleaning the sewer.

In addition to the fatal accidents just enumerated, many sewer men have barely escaped with their lives by retreating from below before the gas overcame them, suffering only temporary inconvenience or injury. All these accidents are reported in connection with sewers that were being cleaned, or needed cleaning. In the Report of Mr. Baldwin Latham on the Sanitation of Bombay a list of 91 lengths of sewer appears, of which 82 contained silt in depths varying from 2½ inches to 51 inches. This silt contains a large amount of organic putrid matter, and in the evidence at the Coroner's inquests the disturbance of the silt is stated to be the cause of the discharge of gases that proved fatal.

The atmosphere of the sewer is generally so foul that man holes are kept open for two hours before the men are allowed to enter.

The usual tests for Carbonic Acid and for Sulphuretted Hydrogen are used previous to the entry of the sewer men, but although the papers have only discoloured slightly, the men have subsequently been suffocated so quickly as to point to a sudden discharge of sulphuretted Hydrogen from the mud in which they waded. This would take place without extinguishing a lighted candle. If the discharge were of Carburetted Hydrogen, and sufficient to be fatal, the mixture would have had to be very much stronger than a fatal dose of Sulphuretted Hydrogen, and an explosion would most probably have followed.

Four per cent. of Sulphuretted Hydrogen is sufficient to produce suffocation, while from twenty to thirty per cent. of Carburetted Hydrogen may be breathed for a short time.

A good deal will depend upon the manner in which the gases rise from the surface of the sewage. All gases, passed suddenly through water, leave its surface with a certain momentum due to the difference of weight of the gas and the water, and they will rise in the air at a rate due to their ratio of weight compared with that of air. The rapidity of effect of any poisonous gas will thus depend upon the amount of admixture it has with the surrounding atmosphere—in other words, on the distance it has travelled from its source. If Sulphuretted Hydrogen were disengaged from mud in a sewer by a man walking *against* a current of air, he might traverse a length of sewer in safety, while a man who followed might die of suffocation. If the gas were Carburetted Hydrogen, it would burn without explosion if ignited by a light, carried by the man, at the moment of bubbling through the water. If ignited later on by a second man with a light, after it had time to mix with the sewer air, it would explode if the mixture *had reached, or nearly reached*, a combining proportion. It is impossible to say what amount of sewer air would combine to form an explosive mixture, as in spite of its extraordinary foulness it has never been analysed, but as sewer explosions follow the laws of other gas explosions, something may be learnt from the behaviour of coal gas and petroleum vapour.

London gas, producing a light equal to 16 Standard Candles, when burnt in an Argand burner at the rate of 5 cubic feet per hour, requires 6·4 times its volume of atmospheric air of ordinary purity to consume it completely, reducing it to Carbonic Acid and Water. With one-half of the above quantity of air or 3·2 volumes, it will burn or explode, but with less force, producing Carbonic Oxide and Water.

Wigan Cannel Gas require 9·7 volumes of air to consume it completely, and is subject to the same rule as the London Coal Gas.

Petroleum vapour, another Hydrocarbon of the same class, explodes in the same manner as the Carburetted Hydrogen of the sewers or the Coal Gas, but with a proportion of air resembling that of the Wigan Cannel.

Experiments, made in the interests of shippers, demonstrated that petroleum vapour from the Kerosine of commerce mixed with 5 volumes of air will not explode. With 6 volumes the explosion is feeble. With from 7 to 9 volumes, and with 12 volumes, the explosion is violent, but of varying intensity. With 16 volumes feeble, and with 20 volumes of air to one of the vapour, the mixture will not usually ignite at all.

Although the combination due to combustion is always in *fixed proportion*, resulting in Carbonic Oxide or Carbonic Acid, mixtures of Hydrocarbon with air in a great variety of proportions may be ignited. Any surplus of one or of the other acts simply as a diluent, reducing the rapidity of combustion or mitigating the force of explosion. Perfect explosions of air and gas rarely occur out of the laboratory, and in most of cases only a small part of the mixture has the complete exploding proportions.

A circumstance worthy of note in connection with the fatal accidents already referred to, is that seven out of the eleven deaths from suffocation occurred during one of the two periods of diurnal barometric depression, and four out of five of the explosions took place under similar conditions.

Sewers in this respect are subject to the same law governing the escape of dangerous gases as coal mines, and were the temperature of the sewage a good deal lower, there might be two periods in the day—those of maximum pressure (*see* Plate I.), when men might traverse the sewers with safety.

In Bombay the minimum temperature of the sewers is so high (75·2°) that none are safe if they have a layer of foul silt at the bottom. In the evidence of a witness at a Coroner's inquest on one of the deaths by suffocation, it was stated that the minimum flow of a sewer is between 1 and 5 in the morning, and between 2 and 5 in the afternoon, and that at those times the smells were strongest. This is what might be expected from the other evidence concerning the time of day of the accidents.

One of the cases of suffocation took place in 1882 in a sewer of the Bombay Port Trust, into which hot water from an engine (or boiler?) had recently been discharged with a view to clean it. One witness said, that the water was not hot enough to burn! It would be difficult to find a more effective means of rendering a sewer fatal than by heating its contents, for every additional degree of heat would aid in setting free the gases contained in the sewage. The discharge into sewers of hot fluids from steam boilers, or from any other source, should be strictly prohibited in India at least.

In May 1885 three labourers were suffocated while cleaning a sewer. The evidence showed that there was much steam in the sewer, and that it was hot—probably from the discharge of a neighbouring cotton mill. A contractor's foreman, on being asked to recognise a sample of the sewage, deposed that he had lost the sense of smell. This is very common among men obliged to work among sewage, and must increase the risks they run in performing their duties.

The experience of accidents during 11 years shows conclusively, that until the men are protected by a sufficient air supply against sewer gas, no other precaution will protect them against fatal risks.

Ventilation of sewers for the safety of workmen is unlike any other case in ventilation, and must be treated entirely on its own merits. Tunnels of railways, which resemble them most closely, are only fouled intermittently, and in the intervals of the passage of trains the products of combustion of the locomotive escape, aided generally by the wind, and by the current set up by the movement of the train. In a sewer the fouling is continuous, and in India it is so great as to require special appliances for the protection of the sewer men. Strong currents of air in a sewer should be arrested as much as possible. They indicate the escape of large volumes of sewer gas somewhere. If the outlet is properly protected against the access of the wind, the movement of the sewer atmosphere will be slow.

Wherever the quality of the sewer air is dangerous, even if it be only at intervals, the fullest precautions should be taken at all times for the safety of the men. Diving dresses, such as the Fleuss portable apparatus, may on extraordinary occasions have to be used, but for general use a ventilating fan should be used, capable of discharging air enough either to form a protecting atmosphere around the workmen, or to dilute the sewer air to a safe degree of tenuity. The fan should be able to deliver air with a velocity of ten feet per second, and at the rate of 5,000 cubic feet per hour, for each man working below.

If four men are in the same part of a sewer, then 20,000 cubic feet per hour or 5·5 cubic feet per second is the quantity of air required.

A lightly built fan, with a wheel 36 inches in diameter and 9 inches wide, having a velocity of 146 revolutions per minute, would give the supply of air required. It might be built in the style of a winnowing machine, and mounted on wheels. A canvas hose, like that of a wind-sail, would convey the air below, and an elbow piece of sheet iron should be used for turning the corner from the manhole in the shaft. A syphon pressure gauge should be safely attached to the outlet of the fan, so that the resistance of the work might be seen by the man in charge. The pressure within the sewer should also be indicated by a suitable gauge at the surface. An outlet must be provided for the air at the nearest opening *below* the fan, taking the direction of the air current, and not that of the water, and if the air should issue very foul, a canvas tube in a suitable frame should carry it up vertically to such a height as would allow it to disperse without nuisance. This tube may be stretched around a light wooden square frame built like a semaphore post, and mounted, like a fire escape, on two wheels. The bottom end of the hose, being made like a shallow funnel, will lie round the edge of the manhole, and may be weighted with earth or stones to make a draught-tight joint.

The fan should be made so as either to blow or to exhaust, and to discharge into the canvas shaft if need be, so that air drawn through the sewer might be carried up to a sufficient height before being set free. With such an apparatus any part of a sewer might be prepared for workmen in five minutes, instead of the interval of two hours required by the existing rules of the Bombay Municipality. By means of brattice cloths or their equivalents any part of a sewer might be cut off, as far as air currents are concerned, from the rest, should it be desired to keep the men in for a lengthened period.

When sewer men are struck down by inhaling Sulphuretted Hydrogen, they usually fall in the slime and water in which they stand, and always on their faces; and their chance of recovery is reduced by the sewage which enters their stomachs and lungs. The risk is thus much greater than if the sewer were dry, and Carbonic Acid the only impurity to be met.

Adequate ventilation of sewers would enormously increase the efficiency of the men employed on the work of cleaning, and would reduce in proportion the cost of supervision, which, in India, is much higher than in Europe.

Ventilator pipe heads are of the most various forms, and qualities are claimed for most of them which are little short of miraculous.

They may be divided roughly into two classes:—Those which depend upon the wind to produce an induced current and a partial vacuum within the pipe, and those which depend on a considerable difference of temperature between the outer air and that of the pipe. The hoods above drying rooms belong to the former class, and stove pipe heads to the latter.

In a still atmosphere, or in a very slight wind, an open top gives the least resistance to the escape of a current. Any other form of top gives more resistance; and as in India a still atmosphere occurs so often during great heat, no English pattern should be adopted merely on its home reputation.

A single outlet is better than any other number of outlets of equal combined area, as it causes less friction, and is generally cheaper. A ventilator pipe belonging to a sewer, which needs no protection from rain, should be open to the sky, and if the assistance of the wind is desired, a collar or flange may be attached, sloping downward all round, at an angle of 45°. The collar may have a width of from $\frac{1}{2}$ to $\frac{2}{3}$ of the diameter of the pipe.

The head formed of a T piece, which is very commonly used, has two faults that render it worse than useless. It varies in efficiency with every wind for 180° round the axis of the head, and it offers a convenient lodgment for *birds*.

The head, with a revolving top turning a screw pump within, is of the least value, as, when at rest, the screw within offers as much resistance as two bends to the passage of air. It is only useful in India when turned by power. The revolving cowl, with weather vanes attached, is the best of its class, and, if kept properly oiled, will act equally well in wind and calm weather. The width of the cowl opening should be that of the pipe, and the height at least two diameters. The vane should be double, with a blade projecting on each side of the opening and meeting behind. It should be carefully balanced, so as to turn freely in a very slight wind.

Ventilator pipes discharging warm or hot air should in every case be protected from the entry of rain, as rain rapidly reduces the interior temperature of any chimney. A conical cap is one of the best and simplest forms. It should be fixed as high above the tube as possible, consistent with excluding the rain. A flat plate, fixed at a height of one-fourth of the diameter of the tube, will give an opening of area equal to that of the tube, but it is preferable, with a view to reduce loss by friction, to make the height of opening equal to one-third of the diameter of the tube.

The history of the Bombay sewers, and the experience obtained in their supervision, should be of the greatest value in the preparation of future work. By silting due to insuffiient velocity of current, the 8′ 0″ × 5′ 4″ main sewer had in 1890 filled up to the extent of 5′ 3″ with mud and sand, reducing the area of the sewer by 65 per cent., and with it the grade and efficiency. The deposit of silt and putrescible matter, which was intended to be carried away by the water, transformed the sewers into a large underground gas works, and considerably reduced their sanitary value, besides involving outlays for ventilating and cleaning that were not originally contemplated in the scheme of drainage.

When they were laid, there can have been very little experience of the behaviour of silt in sewers in a tropical country to go on, and it was doubtless assumed that waste material would be carried by waste water in much the same manner in Bombay as in London. It has been found that the active putrefaction that goes on in the Bombay sewers reduces the organic matter to a gluey consistence, which binds the sand together into a silt that no ordinary flushing will remove. The solid matter which should flow out with the water is arrested in the sewer to putrefy, instead of being swept to the outfall. The delay of the escape of solid matter may be ascertained from the intervals between the cleaning operations.

The silt, instead of being brought to the surface through manholes and carted away, which would be very costly, is moved slowly along the invert of the Bombay sewers by means of a wooden frame, which fills about one-half of the sewer, damming up the liquid, so that it falls over the lower end of the frame with sufficient force to loosen the silt immediately in front of it. The frame is drawn slowly down the sewer by means of a winch, and the silt is thus washed towards the outfall.

The rate of silting is naturally increased behind this moving dam, and the disturbance of the silt below it increases the discharge of sewer gas.

The present rate of movement of silt or sludge in the masonry sewers of Bombay varies from 2 to 10 days for 200 feet, the distance between two manholes. At this rate it would take from 52 to 264 days to travel one mile in front of a scraper. The average rate is less than 50 feet per day, or 105·6 days, to travel one mile. This is equal to 3·4 miles a year. The deposit that enters the pipe sewers is the same as that which lodges in the masonry sewers, and it has to be cleaned out by hand labour and with hand tools. The rate of movement is about the same.

All the masonry sewers are already laid, but only about one-fourth of the pipe sewers are laid that would be needed to serve the whole of Bombay. The quantity of silt that may be expected to fall into the masonry sewers is thus much greater than at present, and its rate of movement towards the outfall will be less than 3·4 miles a year.

The increase of the proportion of urine and night-soil that may be expected along with the extra silt will increase the amount of inflammable gas produced in the sewers, rendering them more dangerous than at present (*see* p. 103). The solid organic matter arrested among the silt is the material that it is most desirable to remove expeditiously out of the city, on account of its unwholesome and dangerous influences. A current of sewage with a velocity equal to 3 feet per second is supposed to be able to keep the invert of sewers clear of deposit; this velocity is equal to a speed of 2 miles an hour, but as the author has not been able to hear of a single underground self cleaning sewer in all India, it is clear that data based on English practice are not safe as applied to the flow of sewage in the tropics. Underground sewers exist at Kaira, Ahmednagar, Nasik, Poona, Talegaon, Sholapur, and Sukkur, most of which are irregular and defective. At Kaira, Sholapur, and Belgaum the sewers are opened annually and cleaned. The silt, therefore, stations on an average six months within them.

Were the whole of the Bombay sewers cleaned out in one day, so that they might benefit by the actual inclination of their inverts, it is not probable that they would remain clean, as although the Bombay waterworks are now complete, there is not water to spare for the extra flushing that would be required. The present condition of the Bombay sewers may, therefore, be regarded as permanent, unless some means are discovered by which the sewage may be made to flow to the outfall with a velocity that will prevent all deposit.

If it is not possible to make underground sewers self cleaning, there seems to be no alternative but to pump the sewage through cast iron pipes, and thus render the velocity of current independent of gravity.

In the meantime it is quite useless to quote statistics of the reduction of mortality in England, due to the introduction of sewerage in large towns, and to expect similar results in India. Everything is different, from the 30° of increased mean temperature to the habits of the people; and while in London the temperature of the sewer is so low as to check and retard putrefaction, that of most Indian sewers is so high as to stimulate it to great activity.

Mr. Glaisher found that at 12′ 8″ below the surface near London the mean temperature of January was 13° higher and of July 15° lower than at the surface corresponding to temperatures of 52·8° in January and 45·8° in July.

Few Indian towns are so well situated as to have ample fall for their drainage in wet weather, and through underground sewers. Sewage must be got rid of daily, for the temperature is too high to permit it to be stored while awaiting the fall of a flooded river. During heavy rain, the river, and not the land, must receive the sewage, in order to avoid the risk of its flowing off the land. It is probable that in many cases a satisfactory fall will only be obtained by an extensive use of open drains between the house and the underground sewers. It may also happen that a sufficient amount of water may be available for the personal needs of the people, but not enough to ensure the cleansing of a system of underground sewers. A very careful estimate of the minimum quantity of water required for one person per day has been prepared by Dr. Hehir of Hyderabad in the following details:—

	Gallons.
Drinking and cooking	1
Washing dishes and utensils...	1
House cleaning	2
Clothes washing	3
Personal cleanliness, including douche bath ...	5
Cleaning privy pans and privies	1
Total...	13

Ten per cent. of this will disappear by evaporation, leaving only 11·7 gallons, a quantity which would not suffice for an underground sewer system. One skin of water or 7½ gallons per day is considered a fair average supply at Cawnpore by people whose washing of clothes and person is done principally at wells and *ghats*.

In the North West Provinces, where waterworks have been established in several towns, remarkable reductions of mortality have taken place.

In Burdwan the Administrative Report of the Chairman of the Municipality for 1886-87 states that the mortality of the town having a population of 34,400 was 24·3 per thousand, being equal to a reduction of 35 per cent. since 1884-85. The death-rate in Bombay in 1888 was 25·16, and in Calcutta between 25 and 26.

The mortality of Burdwan for the year 1891-92 is quoted officially as 43·13 per thousand: the cause of this great increase is unexplained.

In Agra and in Allahabad, where waterworks are now established, there has been a remarkable improvement in public health. Cholera is said practically to have disappeared. The available returns of mortality are dated to 1891, the year in which the Allahabad works were opened. Agra, which had a very bad water supply from brackish wells, and was unhealthy in consequence, shews a mortality in 1891 of 25·82 per thousand, as against an average of 32·23 for the previous five years. In Cawnpore and in Lucknow cholera is still endemic.

The completion of the waterworks in the two latter towns will, in all probability, have results as satisfactory in reduction of mortality as those already realised at Agra and Allahabad. The history of modern water supply in all Indian towns shews that epidemics lose their intensity and that mortality declines in a remarkable manner.

None of the large towns in the North West Provinces are provided with underground sewers, so unless the introduction of waterworks has been accompanied by greatly improved conservancy, the reduction of the death-rate may be fairly attributed to the improved water supply.

While recognising the respective merits of water supply and underground sewerage, it is important to consider them as much apart as possible, in order to arrive at an idea of their respective values. Underground sewers will not work without a good water supply: they will, on the contrary, become a costly nuisance—a series of settling tanks—from which the solid matter of the town sewage will have to be removed with much labour. After some experience it will be found that up to a certain limit of area and population, open drains, properly built, will carry off the sullage and storm water of a town in the most satisfactory manner, and even in large towns, if the experience of Bombay house connection is of any value, a considerable amount of open gutters will have to lie between the houses and the sewers (*see* p. 88).

Open drains involve the collection of fæcal matter by manual labour and its removal by carts, a system against which much has been said and written.

Although undesirable, it may frequently be the least of two or more evils between which a choice must be made. So much of the offensiveness of this service depends upon its organization and supervision, that with the better management that is coming into Municipal affairs, and the improved appliances that are now to be had, such as sewage carts and latrines, many of its most objectionable features may be reduced, if not entirely removed.

A defective drainage system during a period of epidemic becomes a terrible factor in promoting the spread of disease and in delaying its extinction.

During the cholera epidemic in Egypt in 1883, a special commission, composed of influential inhabitants and officials, was appointed in Alexandria to devise means for the protection of the people by sanitary precautions. As the sewers of the town were without any fall, and built with flat top and bottom, the whole of the sewage precipitate remained in the sewers, and had to be removed periodically by manual labour. No syphons intervened between the sewers and the street gratings, and the stenches that issued were exceedingly offensive. It had been the custom for many years to close all the street gratings with mortar and stones during the dry season, thus driving the smells through covered cesspits into the latrines of private houses, which (latrines) are, in half of the houses, situated in the kitchens.

The commission, therefore, to relieve the gas pressure on the houses, had a number of wooden shafts made and placed over street gratings, but the houses being all of several stories in height, and the shafts being only 18 feet high, the gases were carried in at the first floor windows, and several fatal cases of sewer gas poisoning put an end to the experiment.

An iron shaft, about 50 feet high, with a fire at the base, was fixed over the remote end of one of the main sewers. All the air to supply the fire was drawn from the sewer, and for a certain distance along its course the escape of sewer gas was stopped, but as the branch pipes and their openings were not systematically trapped, much good air was drawn in and proportionate loss in effect sustained.

The commission was persuaded by an amateur sanitarian to try the purification of the sewers by means of steam from a portable boiler, and a flexible hose, which he passed through a wooden lid placed over a street gully opening. The experiment lasted only a very short time, the amateur being mobbed by the infuriated people whose houses were being filled, through the latrines, with the steam of cooked sewage mud.

Attempts were then made to wash out the sewers with sea water by means of centrifugal pumps, driven by portable steam engines. For many days 64,000 gallons of water per hour were pumped in at the principal outlets, and disappeared, without filling up the sewers, through the pervious masonry of which they were constructed, into the subsoil of the town.

All the subsoil water of the town is contaminated with sewage.

A member of the commission, reputed to be the wealthiest house proprietor in the town, was rebuilding some of his property that had been destroyed the previous year in the great fire that followed the bombardment by the British fleet. He was found to be using water out of a neighbouring sewer to mix his mortar, in order to save the cost of taking it from the Water Company. He was censured by the commission for reckless use of foul water.

Soon after this circumstance he presented a petition from a large body of Arab inhabitants, praying for the disuse of carbolic acid as a disinfectant. The smell was so revolting to the petitioners that they could not stand it, and it caused their women to miscarry!

It is not often that Orientals protest formally against a smell of any kind.

It is well worthy of note that the ground floor of the house built with sewage mortar was first occupied by a family, who all died of typhoid fever shortly after taking up their residence.

The members of the special commission were drawn from the classes which have since provided Alexandria with a Municipal Council: all, doubtless, good men of business, but many of them quite unversed in the arts of city government.

The extent to which the benefits of a good water supply may be reduced by bad sewerage have not yet been sufficiently examined, but Madrid, having an excellent water supply taken from a mountain stream 32 miles away, had a very severe visitation of cholera in 1885. Cesspits had already been abolished, all dry refuse was removed by carts at night, and a law had been enacted compelling all soil pipes to be trapped. The death-rate in 1888 was still 45, and a careful examination of the sewers resulted in a report that the sewers were built of bad and porous bricks, and that they were of a form that rather encouraged stagnation. They were only ventilated through the gutter openings. The house connections were as defective as the sewers themselves. Instead of a watertight glazed pipe, there was a square brick drain large enough for the passage of a boy. It passed under the house, and the soil pipes were not ventilated. Madrid, with its elevated position, excellent water supply, and apparently good conservancy, had a normal death-rate of 45, which is higher than the normal rate of Cairo (44·77) quoted on page 43.

Cairo is 66 feet above the sea, and has a mean temperature of 72·3°, while Madrid is at 2,175 feet above the sea, and has a mean temperature of 57·6°. It is, therefore, probable that were the temperature of Madrid raised to that of Cairo, the mortality under the conditions just described, of Madrid, would have been much greater—probably equal to that of Cawnpore (54 per 1,000).

Considerable diversity of opinion exists on the subject of the passage of sewer gas through the water of syphons by absorption on the sewer side and discharge on the street or house side. No experiment on the subject has been made in India, and the opinions have evidently been imported from Europe.

As the temperature of water has a most important influence on its power of absorbing gases, the difference between the temperature of sewage in India and elsewhere must be taken into consideration.

Box, in his "Treatise on Heat," states, that if water, or ale, at 32°, saturated with Carbonic Acid, be heated to

68°, it would discharge one-half of the gas it previously held. Similar results are given by other gases. Thus, at 32° a cubic foot of water absorbs of

Nitrogen	Oxygen	Carbonic Acid	Carbonic Oxide	Sulphuretted Hydrogen	Sulphurous Acid	Air
·024	·0411	1·797	·0329	4·371	68·86	·0247

cubic feet; but at 68° F. these volumes are reduced to

·014	·0286	·910	·0231	2·905	36·22	·0170

cubic feet, respectively. It is remarkable that the amount absorbed is a question of *volume* of gas, and not of *weight*, that is to say, the volume absorbed is the same, whatever the pressure or density of the gas. Aërated waters are made on this principle.

Cold air, therefore, not only retards putrefaction of sewage, but increases the capacity of the liquid for absorbing gases, while heat increases putrefaction, but decreases the capacity of water for holding gases.

In tracing out the details of application of a water supply in any town with modern works on a well-recognised scale, the amount of water that is wasted is sure to strike the observer. He will observe in the largest of Indian towns that more is needed for flushing sewers, that is to say, for carrying off sewage, than for the other legitimate needs of the town.

For instance, a 20-gallon supply would be ample for Bombay, if the sewers had not to be provided for, and yet, with a supply of 41½ gallons per head of population per day, the sewers cannot cleanse themselves, although assisted at the mouth by powerful pumping machinery. It seems that since the pumping engines were built, the volume of water in the sewers has been greatly increased to improve the flow of sewage, and thus the engines have been overpowered. Were the power applied at the other end of the sewage sytem, instead of at the outfall, no flushing water would be needed, and the sewage and sullage, which would not exceed 18 gallons per head, could be discharged through cast iron pipes to the outfall at the required velocity, and with a diminished engine power, on account of the smaller volume to be dealt with.

The cost of the extra water supply of 23½ gallons per head, which make up the present supply, would have gone a long way towards paying for a system of iron pipe sewers, which would remove the whole of the sewage of Bombay without the drawbacks of the present system.

It is easy to be wise after a fire, an epidemic, or a great disaster. The Bombay sewers were projected long before airtight sewers were developed, and were doubtless planned on the best existing models. Today they are of more value to the sanitary student in India than all the works that were ever written in Europe. They exhibit phenomena which are not to be found anywhere else in the world, and their scientific history, were it well written, would solve many of the difficulties that surround sewerage projects in India at the present time.

In spite of all that have been built, gravitation sewers are still in the experimental stage in India. The intention of the engineers who designed them has not been realised, for they are not self-cleansing. That they can be made self-cleansing by means of a greater fall than is found necessary in Europe no one will doubt, but one of the great difficulties in Indian sewerage has been to provide a fall equal to that used in colder countries. All sewage must be removed *more rapidly* in Tropical than in Temperate countries, and the sewers must be kept *cleaner*, if we are to benefit fully by the money spent on them. Already the water demanded for washing away sullage and sewage through masonry sewers far exceeds that required for all ordinary purposes, and unless two separate services are provided, the sewers must be flushed with drinking water. If, as is not unfrequently the case, pumping has to be resorted to at the outfall, the increase in the volume of the sewage due to dilution with flushing water involves a greater outlay in pumping plant and fuel for its removal. The cost of waterworks designed with a view to providing flushing water for an underground sewerage system is necessarily much greater than it would be without it. The question must, no doubt, have frequently arisen, whether, after all, the underground masonry sewer is the right means for removing sewage in India. The total available fall for sewers in an Indian town is generally less than the fluctuation of level of the river into which they are to discharge, and if the sewage is used for irrigation there is scarcely a town in India that is so conveniently placed as to dispense with pumping. Iron pipes have by universal consent been recognised as the best means of transporting potable water from its source to the consumer, and iron pipes are already establishing a claim to be regarded as the best means for removing the same water innocuously, after it has served our purposes. The cost of iron pipes in India, and the novelty (at present) of the removal of sewage in iron pipes, stand somewhat in the way of their chances of adoption, but once the safe and easy transport of sewage in iron pipes is demonstrated in India, no difficulties in the details of the system will prevent its adoption. Questions of methods of propulsion, of valves, catch pits, strainers, and mode of collecting the sewage will all be settled experimentally in the country as other similar details have been settled. If the Bengal Ironworks is able to deliver pipes for low pressures at anything near English foundry prices, the transport of sewage by pumping will be greatly facilitated.

CHAPTER VI.

LATRINES AND PAIL DEPÔTS.

It has been aptly said that the best measure of the civilization of any country is to be found in the state of its privies. A journey through half a dozen different countries will prove that the statement contains a good deal of truth.

Well designed and well kept latrines, of whatever kind, are the evidence of a public taste for order and cleanliness, and a clear apprehension of the first essentiasl of hygiene.

There is no *best kind* of latrine—unless a cultivated field could be so designated ; but, as traditional custom leaves its mark even upon our simplest natural functions, the design of a good latrine involves a very considerable knowledge of human nature as well as of natural phenomena.

Beginning with the human factor, latrines in India are associated with a very low caste of men and women, to whom all the work of removing nightsoil belongs. The work, and the workers, are equally despised, and the whole subject is avoided by respectable Natives.

Sanitary questions of this class are distasteful to them, and they would rather let their latrines become a nuisance in the house than take any active interest in keeping them clean. It is no wonder, under these circumstances, that Indian latrines are filthy, and productive of much mischief. In houses of more than one storey a vertical shaft is built into the wall, passing through the various stories into which the night soil is discharged. It falls into an iron pan, at the foot of the shaft, which is emptied from time to time by the sweeper or *mehter.* This vertical shaft gets fouled by the discharge passing through it ; it is never cleaned, the brickwork is saturated with urine, and it becomes very frequently a ventilating shaft, delivering very foul air into the house. In other houses the excreta are collected by the sweeper directly from bathrooms, and carried away either in an earthenware vessel or in a watertight basket. In public latrines excreta are collected in earthenware or metallic vessels, and carted away in tank carts of special construction.

Among the poorest classes living in towns, it is impossible to have latrines attached to each house. They could not be kept clean, and many of them would soon get into such a state of filth that even the tenants would cease to frequent them. They would then become simple centres of infection. Public latrines, therefore, become one of the most important sanitary necessities of an Indian town. Their design, distance apart, arrangement for the separation of sexes, and provisions for superintendence and cleaning demand the greatest care on the part of the authorities. The principal drawback about the public latrine is that it does not make any provisions for young children, who regularly use the open street, even in the largest towns. It has been found impossible, so far, to stop this practice, which helps to keep up the traditional bad habits of adults.

It is a common error among Europeans to suppose that Natives have no aversion for foul stenches and sights. It will be found in many places that when the poorer classes avoid the public latrines and urinals, it is because they are so very filthy as to offend their very insensitive *habitués*. This should be taken as an encouraging sign, by the sanitary engineer, of a taste that should be strengthened by the better construction and management of latrines and urinals. As long as municipalities look upon excrementary matter as so much useless material, to be got rid of by means that demand an outlay of so much per annum, the halalcore service is likely to be carried out in a more or less perfunctory manner. But when once they realise that nightsoil has a market value far beyond its cost of transport to the cultivated lands in the neighbourhood, they will have an interest in the proper supervision of both urinals and latrines, which, it is to be hoped, will entirely alter their general appearance. In order that the cultivators may adopt nightsoil as manure, the municipalities will have at first to take the initiative by taking a certain area of land in hand, and shewing what can be done with sewage manure applied in the best manner. This has already been done in Madras, where an annual profit is now made by the municipality on its sewage farms (*see* p. 150). The method by which excrementary matter is removed from the town, whether by sewers or in carts, will decide in what way latrines and urinals should be constructed. If in a town, having already a pipe supply of water, and a prospect of underground sewers, they should be designed to convert, when necessary, from manual service to sewer service with the smallest outlay.

In determining the privy accommodation necessary for any part of a town, the value of one stall, or seat, must be ascertained, and the latrine afterwards becomes a multiple of the seat. Four hours in the early morning, from four o'clock until eight, will include the visits of

90 per cent. of the people. The other 10 per cent. may be distributed throughout the day. Four minutes may be taken as ample time for the duration of a visit, therefore one stall in four hours will accommodate 60 persons. One-ninth of this number in addition use the seat in the course of the day, making in all $66\frac{2}{3}$ persons per stall, or 15 stalls per 1,000 of population. If three minutes be taken as the duration of a visit, then 12 stalls would serve for 1,000 persons daily. Public latrines are always made after a town is built, and it is not easy at all times to find suitable places for their construction. Their distance apart should not exceed 700 feet, and their size will vary in any part of a town with the proportion of the population who use them.

The insufficient provision of public latrines has, in various towns in the interior, given rise to the establishment of private latrines by men of the sweeper caste, who make a very small charge to the public for their use. They are, as a rule, defective in design, badly built, and badly kept. It is to be hoped that they will soon be superseded, and that the sweepers who have been enterprising enough to establish them may find a more remunerative occupation in the transport or the utilisation of nightsoil.

The essential points in the design of latrines are that the part that is soiled shall be as small as possible, and that the soiled surface shall be non-absorbent. These considerations are too frequently overlooked, and the consequence is that the latrines are always offensively foul. A cheap and durable waterproof surface may be produced on good Indian brickwork by treating it, when dry, with a solution of hard pitch in a volatile solvent, like mineral naphtha or kerosine. The solution should be as thin as new milk, so as to penetrate a good eighth of an inch into the brick. The floor, platform, and the walls may be thus treated, the latter to a height of 3 feet. Above, the interior surfaces should be lime-washed, as well as the exterior. Latrines cannot be too well lighted, and the ventilation should be as thorough as possible. Interior partitions should not be more than 5 feet high, and openings should be so arranged as to have, if possible, a current of air through the stalls. In the North West Provinces the men prefer to be screened entirely in their latrines, while the women object to all partitions. The latrine for females is thus more easy to keep clean than the other. The platform on which the individual rests must be made in such a way that the feet can only take a certain place on each side of the whole in the platform. The platform seat, or "trou de Turc," is the only kind that can be used in public latrines, and the person, once in position, should have very little room for lateral movement. For this reason, and on account of the scarcity of space in towns, the stalls should be made as small as possible, but with a view to ventilation there should be plenty of head room and large openings to the air. Latrines connected direct on to a sewer may have the platform built over a long trough, flushed automatically, into which all the excreta, liquid and solid, fall, or they may be built each with a separate pan, with its own syphon, discharging into the pipe sewer. Each separate pan will in this case require separate flushing, and although the cost in water is less, the cost for apparatus is necessarily more than with the continuous trough.

The unconnected latrine served by manual labour is fitted with a movable pan which slides below the platform and serves to catch all dejections, which are emptied into an iron drum to await the arrival of a tank cart, into which they in turn are emptied. The pan is washed and returned to its place. If the stall is properly built, and the pan (of sheet iron, well tarred) is of the right size to fit its place, so as to catch all excreta, the latrine may, with reasonable attention, be kept clean, but in the majority of cases nothing fits, and nothing is right. The floor is of earth, the pans of porous burnt clay, and too small, and the smell, for many yards around, is horrible. The attendants, who are obliged to live in huts adjoining such latrines, are much to be pitied.

They are as necessary to the community as the police, while they are worse lodged than the lowest thieves and prostitutes. It will be found convenient and economical to build latrines for men and women on opposite sides of a partition wall and under one roof. This wall can be used to carry a long flushing tank or trough serving both sides. There are several methods of flushing pans direct from this trough. In every design for new latrines there should be included a suitable shelter for the attendants during the day, and a lodging fit for human beings, if they are to live on the spot.

Municipalities should provide a sufficient number of latrines and urinals within their limits, and provide also for their strict supervision, before taking active measures against the inhabitants for committing nuisances in the streets. A town only partially provided with places of public convenience will shew very little improvement in the appearance of its streets, in consequence of the outlay, and even if well provided with badly kept privies and latrines, the streets will continue to be used as before, and conservancy will be discredited. Pail Depôts are of two kinds: they may be tank carts receiving the contents of pails of nightsoil brought by sweepers from private houses, or they may be basins built to receive pail contents, and discharging into a sewer. Both are valuable in reducing the distance that the sweeper has to travel on foot with his unsightly and often foul-smelling load.

The basin, like the latrine, should have the smallest possible area exposed to the contact of sewage. It should, in fact, be as small as is possibly consistent with the work it has to perform. Pails are brought full to the basin, and must be emptied, washed, and removed as quickly as possible. The washing water should be sufficient to dilute the excreta with about 15 times its volume as it enters the sewer.

In a design prepared by the author for Cawnpore, the basin was 4′ 9″ in diameter, built like a bowl, in brick, with a tar coating as already described. A 6″ grating, with 3″ × 1″ openings at the bottom, communicates with a 4″ syphon and glazed earthenware pipe. A light iron frame crossing the basin near the top provides support for four pails, which can only be placed in the proper position. The pails are emptied and placed, mouth downwards, on the support, and, on the turning of a cock within easy reach of the sweeper, a strong jet of water from below washes out the pail, the water falling into the basin. At the same time, a jet at very low pressure falls on the outside of the pail, washing the exterior. Reckoning a pail to hold the sewage of 20 persons as collected at present, this depôt would serve a population of 7,000 people by working 6 hours a day, and allowing 4 minutes for each operation.

In towns where the water supply is intermittent there is a risk of nightsoil being drawn into the nozzle over which the pails are emptied, if the pumping happens to stop while work at the basin is going on. This risk may be entirely obviated by putting an ordinary retaining ball valve in the supply pipe of the depôt; this will arrest any return flow of the water. A pail depôt may be conveniently attached to a latrine and put under the same supervision.

Syphons attached to latrines in India have almost always too much seal. The same class of syphons is used for everything, with a seal ranging from 2 to 3 inches, while in many cases the necessary dip is nearer half an inch. A latrine on the ground level, with a ventilating pipe in the pipe sewer leading from it, could never be exposed to a current of sewer gas that would blow through a half inch seal, equal to 2·6 pounds per square foot. The less the seal, the less will be the risk of blocking up, and also the quantity of water required for flushing.

Latrines in storied houses should always be connected to a vertical drain continued to the top of the house, and open. It should be larger in diameter than the branch to the latrine, so that no solid matter that may be put into the latrine may block it. The seal of the syphon between the latrine and the down-take pipe must be greater than that of the public latrine just described, as the discharge of a pail of water suddenly from an upper floor would compress to a certain extent the air below it, and influence, during the period of its descent, the equilibrium of the seals in the lower stories. If the down pipe is of earthenware, the joints may be made of tarred gasket and run in with hot pitch. If of iron rain pipe, as is most frequent, the joints should be caulked with tarred yarn to within 1½ inches of the mouth and run in with hot pitch, which will not run at a temperature of 160° Fah., for this is the temperature to which iron is exposed out of doors in India. It would be better, on account of the permanent foul lining of these pipes, that they should not be exposed to the direct rays of the sun.

CHAPTER VII.

THE REMOVAL OF SEWAGE BY PUMPING, AND SEWAGE IRRIGATION.

The pumping of sewage was first resorted to when difficulties arose at the outfall on tidal rivers, requiring it to be lifted a few feet, in order that it might flow away to the sea.

In later years pumping was employed with a view to the prompt and rapid removal of sewage through iron pipes, in order that it might be cut off from communication with the air almost as soon as produced, and isolated until it reached its destination.

This system resembled a secondary waterworks, and might have been at first suggested by the water supply. The application of pumps and iron mains to the removal of sewage at once overcame all difficulties of grading and levels, and the question was reduced to one of volume to be removed, friction of pipes, and height of lift.

In Europe, and especially in England, where the underground temperature is always below that necessary for active decomposition, the rapid removal of sewage was calculated to stop the escape of foul gases from house pipes and connections, which are liable, in warm weather, to be heated above 45°, and which have been observed to be much more offensive than main sewers, in which many men spend their working days without apparent injury.

The amount of warm water used in English houses promotes active putrefaction in house connection by keeping up the temperature.

Although the various systems of pumping known in 1886 were all proposed in that year for the removal of sewage in Cairo, the influence of underground temperature in promoting the active putrefaction of sewage has only recently been observed in connection with iron sewers.

In the tropics, therefore, the removal of sewage from towns by means which cut it off from all communication with the air, acquires a greatly increased importance, and becomes, in many cases, the *only* means by which it is possible to remove the liquid refuse of a town without injury to the inhabitants. When the sewage has to be used for irrigation, the rapidity of transport that is obtainable by pumping enables the liquid to be put on the land in the least offensive condition.

In comparing sewage farming in England and in India, the difference due to rainfall alone must be carefully considered. The rainfall in England is distributed throughout the year, and on an average suffices for the needs of the cultivator. The application of manure in a highly diluted state to any but light and well-drained lands has frequently been found to be positively injurious, and has earned a bad name for sewage farming.

In India, for many months in the year, there is no rain at all, and this condition, accompanied by a high temperature and rapid evaporation, renders regular irrigation absolutely necessary where crops have to be raised. Cultivated land in India is nearly always impoverished for want of manure, and if the manure can be supplied in the process of watering, the labour of application and the cost are reduced to a minimum.

The Liernur System was first applied in Amsterdam by Capt. Liernur, and has been tried in the Hague and in other places. In this system, only the excrementary matter is removed from houses and latrines, leaving the sullage to be disposed of by other means. The urine and fæces were either pumped direct to a factory, where, by means of apparatus closely resembling a sugar battery, they were converted into poudrette, or they were conveyed direct to arable lands and ploughed in to a depth that placed them below the crops. The cost of carriage is thus reduced to a minimum, and the most valuable of all manures is distributed in the earth before it is allowed to depreciate by decomposition. Two systems of drainage are thus needed in a town, and although the Liernur System realised all the inventor claimed for it, the municipality of Amsterdam reported in 1885 that in rejecting sullage, it failed to meet all the requirements of the town. This report was addressed to the Governor of Alexandria, at a time when Captain Liernur had proposed to remove the whole of the nightsoil of the town gratis, on condition that he would receive a grant of ground upon which he might establish his poudrette factory. It was finally determined that it would not be prudent to make the removal of the nightsoil of the town dependent on the success of a commercial venture, which, however well it had succeeded at Amsterdam, was surrounded by many new conditions at Alexandria, of which the influence was at the time unknown.

The Liernur method of collecting pure nightsoil, unmixed with water, rendered it possible to convey it by cart or rail to considerable distances. In a work entitled "The Sewage Question" (Longmans, 1867), Mr. F. C. Krepp demonstrates that the sewage of one person for one year is worth ten shillings as a fertiliser. It would weigh 746 lbs. in barrels, and would bear the cost of 180 miles of transport by rail at one penny per ton per mile. This method of distribution would be useful in a country where the rainfall is sufficient for the purposes of irrigation, but in hot countries, having long periods of dry weather, the whole of the sullage, together with the nightsoil, should, when possible, be distributed on cultivated land.

The Shone System, already in use in many English towns and in Rangoon, is composed of a closed vessel of cast iron, into which the sewage and sullage from all the houses, on a certain area of ground, falls by gravity. When the vessel is full, a float within rises with the surface of the sewage in the vessel, and opens a valve which admits compressed air from a special main. The compressed air, acting on the surface of the sewage like a piston, forces it out of the vessel (called the ejector) into the iron main leading to the outfall. The air compressing engine may be located at any convenient place, and the compressed air, unaffected by weather or climate, is led to the ejectors in any part of the town.

It is claimed for this apparatus that no separation of materials that pass through it is necessary. Sticks, sand, gravel, and vegetable refuse may all fall into the ejector, and will pass out with the sewage, leaving no residue. No additional flushing water is needed, as in the case of masonry sewers. The economical limit of pressure of the air employed is 30 pounds per square inch, and it is claimed, as an additional advantage accompanying the use of this system of distributing power, that it may be used for other purposes, such as driving small motors, for lifting, hoisting, ventilating, printing, &c.

Having done its work in the motor, the air escapes at a considerably reduced temperature, depending on its original pressure in the main, and can be again utilised for the cooling of food and water.

The Berlier System, named after its inventor, has had a considerable success in France, having been applied in Lyons, Paris, and elsewhere. It was fitted up at the Pepinière barracks in March 1881. When typhoid fever was epidemic in Paris in the autumn of 1882, the Pepiniere was the only barrack which had not a single case of typhoid among the thousands of soldiers stationed there. To have saved a barrack in Paris at such a time from the fever is no slight testimony to the sanitary effect of the Berlier System of drainage. The apparatus consists of a metallic cylinder placed in a cellar at the foot of the vertical house drain. This cylinder receives the whole of the sewage and water from the house, and it contains a screen which arrests all solid matters that would be likely to interfere with the valves of the apparatus. The screen is accessible for periodical cleaning. The cylinder communicates with a chamber containing a valve attached to a float, so that when a certain amount of liquid drains into this chamber, the float is raised, and with it the valve, allowing the liquid to be drawn by a partial vacuum into the iron sewage main leading to a pumping engine, placed in any convenient position, from whence the sewage may be forced to the outfall. When the Berlier System of sewage removal was first tried, grave doubts were expressed as to the economy of using a partial vacuum for the transport of sewage in iron pipes.

Engineers naturally apprehended serious leakages at the joints, and as the maximum working power of a vacuum would not exceed 27·0 inches of mercury, or 30·5 feet of water, a force equal only to 44 per cent. of the maximum economical pressure (30 lbs. per square inch) used in Shone's apparatus, an experiment on a large scale was made in Paris.

Six-inch pipes were laid from Levallois-Perret to the Place de la Concorde, a distance of 4,206 yards, the joints being all soldered. The pneumatic pump drew through the pipes 134 cubic metres of matter taken from cesspits in 3h. 50min. The velocity of current was equal to 2·56 feet per second, and the vacuum at Levallois-Perret was equal to 65 centimetres of mercury, or 10·6 lbs. per square inch.

It was found that the actual force required to pass the liquid through the 4,206 yards of pipe, as measured by vacuum gauges at each end, was less by 33 per cent. than the calculated resistance by Prony's formula. This difference has not been further explained.

The tubes lay on supports within the main sewers, where they travelled in the same direction, and there they would be exposed to the changes of temperature of the rain between summer and winter, which would cause a certain amount of movement, equal at least to that of water pipes, and as the joints were practically rigid, some compensation would be needed for expansion and contraction, which would take place as in water mains.

In situations where the pipes are buried in the earth, the joint of Trifert of La Louviére in Belgium may be used with advantage, as it compensates all movement due to change of temperature or slight subsidence while remaining airtight. It has for many years been in successful use on gas and water pipes. An annular rubber ring is slipped on to the spigot end of the pipe, and this pipe pushed home into the next socket. The rubber ring rolls into place, and is flattened to about a fourth of its original thickness in the process, making a joint that is at once vacuum-tight and flexible enough to compensate all ordinary movements. This joint has been much used in Belgium and in France, and has even been used on pipes carrying hot tar in gasworks without injury.

The movement of the liquids in the experiments just described was examined by means of panes of glass, fixed in the sides of the pipe, and letting the light pass through. As described by Mr. Adolph Smith, F.C.S., the *Lancet* commissioner, "the semi-solids are held in suspension during the whole journey, as if something were constantly stirring up the water inside the pipe. This peculiarity has the appearance of ebullition, and is produced by the movement of the air within the pipes, as it is drawn forward by the pump at the works. Thus, says the inventor, the deposits that take place in all other pipes or sewers are prevented. The sewerage, being charged with gas that bubbles up and keeps all the more or less heavy matter in suspension, it is readily carried along, and does not adhere to the sides of the tube. For this reason, syphons passing under or over sewers, pipes, or other obstructions do not give rise to the customary risk of stoppage. The air bubbles change in shape while passing through the syphon, but their progress is not impeded."

No mention is made of the temperature of the sewage in Paris, and we are not warranted in expecting exactly the same phenomena of working from the same apparatus, if established in India. The movement of the liquid sewage, the possibilities of deposit or fungoid growths, the durability of the pipes, the risks of leakage, and the facilities for repair, are all matters of the greatest importance, and have still to be ascertained. The working of the Shone apparatus in Rangoon and in Karachi will, doubtless, furnish us with much valuable information on these points.

The Berlier System has, as has been stated, only about 44 per cent. of the available force for working that the Shone System possesses, but it has only a single instead of a double system of pipes. The risk of escape of gas or sewage from the Berlier pipes by leakage is *nil*, while the Shone sewage pipes being under pressure would leak from a defective joint. The risk of this is rather less than that of waterworks.

The Berlier System, or, we should rather say, vacuum pipe sewers, are best suited for falling gradients, where the force of gravity contributes a part of the power needed to propel the sewage. The vacuum pump must, therefore, be placed as low as possible. When once the sewage reaches the engine house, it is forced by a pressure pump to its destination.

In order to be able to know at all times that the jointing of the Berlier pipes are tight, instruments similiar to a barometer are fixed at various places along the course of the pipes, and joined up with lead tubing. A small float on the mercury column sets an electric bell in motion, if the pressure should fall, and thus calls attention to the fact.

The Cornish and Wallace system of drainage was designed in Cairo expressly to suit the conditions of that city by Mr. J. E. Cornish, C. E., and the author. It combined certain features of the Berlier and the Shone systems. The following description gives an outline of the details :—

The sewage and sullage of one or more houses was to be received by a covered watertight cesspit of masonry, built outside of the houses and below the footpath. This cesspit had a capacity of 3 to 5 cubic metres, and the house drains of earthenware pipe discharged into it. A ventilating pipe passed from the cesspit to the top of the nearest building, and a 3″ or 4″ cast iron pipe connected the cesspit with the vacuum main. The pipe terminated with a valve at the lowest part of the cesspit, and solid objects were arrested by a grated fence surrounding the house drain pipe. The spindle of the valve was extended several feet above the valve, and carried two floats, one fixed permanently at the foot, and the other near the top. For practical purposes, the valve, spindle, and floats were one piece, held in upright position by two brackets having stoneware bushes fitting loosely on the spindle. The valve was of cast iron, enamelled, and the valve seat of India Rubber, so that in no part were two metallic surfaces allowed to work together.

The valve was held to its seat by the partial vacuum in the main, and the sullage and sewage flowing in covered it and the lower float. On reaching the upper and larger one, the combined floating power of the two floats opened the valve, and the liquid passed towards the pumping station. The levity of the lower float being sufficient to keep the valve full open as long as it remained submerged, the cesspit was emptied and the valve closed to repeat the same movement when the cesspit was full. The upper float could be adjusted to open at half full or any other point. The frequent opening of the valve, as in the Berlier System, was thus avoided, and a storage space of some hours' capacity provided in case of accident of any kind. The cesspits were to be supplemented by vacuum tank carts, already in use in the town, which would put isolated cesspits in communication with the vacuum mains. The mains were provided with hose connections by which the carts might be emptied and partially exhausted of air at the same time.

The cesspits were to be part of the drainage project, to belong to the system, and not to the house proprietors.

The principal discharge main lay along the bed of a ditch or canal known as the Khalig, which divides the city longitudinally, forming a natural basin for the drainage of the town.

Between a third and a fourth of the area of Cairo, lies below the level of high Nile, and during the period of flood the subsoil absorbs all the drainage, which escapes as the flood subsides.

The pumping stations established along the course of the Khalig drew the liquids from their several districts and discharged them into the principal main pipe, which would carry them to cultivable land to the south of the city, where every gallon would be of value to raise market produce for the inhabitants.

The average rainfall during 8 years in Cairo has been found to be equal to 1·05 inches per annum. The country is, therefore, for agricultural purposes, a rainless one, and as the wind blows for nine months of the year from the North, the locality chosen appeared to be the most favorable for the site of a sewage farm.

The scheme was based on a population of 323,000, exclusive of the suburb of Boulak, and the quantity of liquid at 100 litres per head per day amounted to 7,109,000 gallons. The pipes were calculated to discharge that quantity.

Used at the rate of irrigation required for cotton cultivation, the sewage of Cairo would be ample for a farm of 1,077 acres.

The work was estimated to cost £3,25,990, or a little over £1 per head, and the annual *working expense* at £15,900, or rather less than one shilling per head of population per annum, exclusive of interest and depreciation.

One of the most important conditions in the drawing up of the scheme was that it must not interfere with the domestic privacy of the inhabitants, or with any of the special privileges which all foreigners enjoy under the "capitulations" of a treaty made by Mehemet Ali with the European powers in order to encourage the introduction of European arts and commerce. These privileges have been frequently abused.

Mr. Baldwin Latham has recommended in India a system of sewage removal by means of pumping, which has special features not to be found in any of the apparatus previously described.

He recommends it to be used in situations where sewage cannot be removed to the place of discharge by gravity. It is well described in his Report on the Sanitation of Bombay, from which the following particulars are taken:—

"The method of transmitting power from one central station to a number of points within the district, where the sewage shall be automatically pumped by means of water at high pressure, will have many advantages in your district, such as the following:—It will diminish the size, depth, and cost of sewers, manholes, and ventilators, and the sewers can have better falls so as to cause them to work more efficiently. The sewage in each district would be pumped locally, and at the level at which it is found, and, consequently, would not be allowed to gravitate to the lowest part of the district to be again pumped up. Only one staff of engineers, engine drivers, and stokers would be required at the central station, which might be at the present pumping station at Love Grove. The water used in transmitting power can, after use, be employed for flushing the sewers, road watering, or irrigation. The water required for the transmission of power may be collected by means of filter tunnels and land drains from the ground, and so a circulation in the underground waters towards some point outside the city would be secured, and the effect would be extremely beneficial to the health of the whole district, and so a sanitary advantage would accrue from being able to get rid of what no doubt has been a source of much ill-health in Bombay. The high pressure water may be used for a number of useful purposes in the district, one of which is the extinction of fires, for, by using a combination hydrant known as the Greathead hydrant, your present low pressure water may have all the force impressed upon it that could otherwise only be secured by steam fire engines. You could also use the power, if required, to pump sea water for road watering at a number of points within the district. Automatic hydraulic pumping must not be confounded with any system in which air pressure or vacuum is produced, both of which methods have special disadvantages when applied to the raising of sewage. Under the hydraulic system a chamber is formed below the level of the streets, in which two automatic direct-acting pumping engines would be placed, which would be actuated by high pressure water. The machines are applicable to every variation in lift, which is not the case with other systems, as all that has to be done is to grade the size of the cylinders to meet every inequality of lift throughout the district. The engines are controlled by floats, and one engine will perform all the work required from it. The second engine is used as a reserve, and the two engines are worked alternately. The floats of both machines are capable of adjustment, so that should one engine become overpowered, the second would come into action of its own accord. The power generated at the central station could be transmitted through pipes to every part of the district, and, of the indicated horse power of the engines used for generating the power, on an average 60 per cent. would be available, and would be realised in actual work done in raising the sewage, and which, by a comparison with the duty got from the present pumping engines at Love Grove, or 36 per cent. contrasts very favourably. The hydraulic machinery is of the simplest character, and not unlike that which may be seen at the docks (of Bombay) performing a variety of useful operations."

By the sectional pumping and division of the district the risk arising from the break-down of the pumping engines is diminished, as by proper arrangement of the sewers one or more districts may be made to relieve any section of the district in which there might be a break-down of the pumping machinery. Mr. Baldwin Latham's system includes the engines and hydraulic pumps of the central station, the pipes conveying water at a pressure of 6 cwt. per square inch to the sewage engines in the various districts, which are placed in pairs in each collecting cesspit or chamber, and the cast iron sewage pipes conveying the sewage to the highest point to which it has to be lifted. Each sewage pump consists of a complete pumping engine, with its hydraulic cylinder, valves and gear and piston, and a sewage pump with its barrel piston and valves, suited for sewage.

On reviewing the various systems just described, it will be seen that their common object is to remove sewage more completely and more expeditiously than is possible by gravitation in masonry sewers. All are designed to reduce the exposure to the air as much as possible, and all use pumps of various patterns and on different principles. Berlier carries the idea of isolation so far as to suppress all cesspits and receivers, and couples his pipes to the down-take pipe of the house, with a simple apparatus intervening. Liernur couples his vacuum pipes direct to the house privy, but has a receiver in the street. The privies are emptied once in 24 hours by a valve man. Shone, Cornish and Wallace, and Baldwin Latham begin to deal with the sewage after it has left the house, and fallen into a closed cesspit or receiver, from which it is drawn by a partial vacuum in the system of Cornish and Wallace to the pumping station, and forced from thence to the outfall, while in the other systems—those of Shone and Baldwin Latham—it is forced, in the former case, by direct air pressure on the surface of the liquid to the outfall, and in the latter case pumped by water-driven pumps to the outfall. The primary motive power is in all cases steam, which is transmitted partly by partial vacuum and partly by direct pressure in the Liernur Berlier, and Cornish and Wallace systems, by compressed air alone in the case of Shone, and by high pressure water in that of Baldwin Latham.

The three first-named use a single set of pipes both for power and sewage, and the latter use one set of pipes for their power and another for the sewage.

It is quite unlikely that any single "cut and dry" system will be found so perfect at all points as to be of general application. They are the outcome of a rapidly growing conviction that sewage must neither be allowed to lie about above ground near dwellings, nor to accumulate in underground passages constructed to remove it to a distance. There is, so far, no concensus of opinion among engineers as to the best mode of applying power for the removal of sewage, and, for the moment, municipalities and local governments appear content to ask only for something better and safer than existing methods. They are even willing to pay more than before in order to improve the public health, but they naturally want some assurance as to the reality of the advantages offered to them.

The sewage pipes are, in every case, of cast iron, a point upon which the several inventors are unanimous. The details and fittings as far as India is concerned are in a state of development at the present moment. The difficulties we hear of from time to time in connection with the Shone System at Rangoon are all of a character that is more or less local, and can be only dealt with by the aid of local experience. The connection of domestic privies in the houses of the lower classes with the pipe sewers of the System seems to be a very risky venture based on a standard of cleanliness that the habits of the people do not warrant. Everything but a proper supply of water will be put into the pans or receptacles until they are blocked; and the possibilities of evil due to a congested domestic privy blocked with contagious fæces in hot weather must be considered in comparison with the daily transport, by manual labour, of a small portion of the nightsoil to a pail depôt, while the bulk of the fæces of the people is received in properly managed public latrines. A single seat of a public latrine will accommodate 66 persons per day (p. 125), and a pail depôt basin 4 feet 9 inches in diameter will serve a population of 7,000 persons (p. 128). There is much less risk of solid materials getting into the sewers through latrines or pail depôts than through domestic privies, while their cost, both for installation and supervision, is only a fraction of that of the latter per head of population.

There is at present only one system on trial in India using cast iron pipe sewers, we are therefore without the means of comparing it with any other known system, and judging their respective merits, for it will not do to compare the working of one system here with another in England. We have, however, to learn how cast iron pipe sewers will deal with such sewage as is produced in Bombay and in Calcutta. How will the interior surface of the pipes be affected, what will be the cleansing velocity of the current, and, if the silt is allowed to settle at times into the gluey mass that has given so much trouble in Bombay, what velocity of current will be required to dislodge it.

It is prudent, at the present time, to determine to be sanitarily clean without expecting to make any profit (except in health) by it, but the time is approaching when sewage in India will be as certain a source of profit to municipalities as land or buildings.

The value of town sewage as a fertiliser has long since been demonstrated by numberless experiments. The best known case of the successful use of human excrementary matter is that of Japan, of which country, Dr. Maron, a member of a Prussian Expedition to Eastern Asia, says :—" Japan is a country about the size of Great Britain, but owing to its mountainous formation only half of it is fit for cultivation ; yet it comfortably supports a larger population than Great Britain without even using the dung of the lower animals or importing guano bones or other fertilisers, the only manure applied by the Japanese being human excrements, which, most carefully collected and utilised, have produced never-failing crops from time immemorial. Since the opening of her harbours to foreign commerce, Japan is even able to export breadstuffs in considerable quantities, while Great Britain is annually drained of thirty-two millions of money by importing food and fertilisers from abroad."

The principal difficulty in the application of town sewage to the land in India has been the question of transport to the site, for few towns are so favorably situated as to be able to turn their sewage by gravity direct on to cultivated land. The pumping of sewage is thus closely allied to the question of sewage irrigation, and as sewage must have the same value in India as in Japan, there can be no doubt as to its success as a fertiliser on ground that is habitually starved in regard to manure.

Fortunately for India, thevalue of sewage manuring is no longer in the hypothetical stage, as the following extracts from the Report of the Health Officer, Dr. J. Nield Cook, of Madras, will show :—

Sewage Farming in Madras.

The idea of adapting the sewage farm system to the needs of Madras was first conceived by Mr. Standish Lee, the Municipal Engineer, in the year 1869. No worse site could have been secured anywhere about Madras than that of the first experiment in the neighbourhood of Choolay. It was a dismal swamp, periodically submerged by salt water, which on evaporation deposited a saline mud. The soil was black, plastic, and as retentive as stiff clay. Not even a blade of grass grew upon it. Prejudice against the use of sewage at that time was such that, had it not been that a large quantity of it had been discharged for a long time into this swamp, it is probable that the commissioners would never have sanctioned its adoption. Certainly, no better site would have had a chance of obtaining their sanction.

The fact that a sewage farm could be made to succeed, even in such an unpromising locality, was demonstrated within a few months of the commencement of the experiment, and conclusively proved the general principle that this method for the disposal of sewage was applicable to the conditions of an Indian town. The first thing that had to be done was to raise the ground above the reach of the water. This was accomplished by depositing street sweepings and covering them with earth dug out of the place. Probably as much as 25,000 Tons of sweepings were used for the purpose. The work commenced in June 1869. In July the first guinea grass was laid down. By the end of August the first crop was obtained. By the end of the year nearly three acres were under cultivation, and by February 1870 nearly four acres were reclaimed. The first reports on the farm were most favourable, but this satisfactory state of things did not last long. With the advent of the hot weather, 1870, evaporation increased enormously, and at the same time the tank waters which had been used to dilute and supplement the sewage fell short. The salt was drawn to the surface. Indeed, the amount of salines in the soil was so great that, even two years after the farm had been put under cultivation, if the soil was allowed to rest for a few days, a saline efflorescence covered the ground. A large quantity of guinea grass perished altogether.

The hurrialie grass was not strong. The only grass that thrived was a course swamp grass that grows on the banks of the Coum River, and is known as cow grass. This is not a suitable fodder for horses, though other cattle devour it with avidity.

Mr. Robertson, the Superintendent of Government Experimental Farm at Saidapet, visited the place with a view to discovering the defects that prevented any real progress from being made. The height of the subsoil water, the temperature of the subsoil, and the condition of the land in various parts of the farm were carefully examined and noted; and it was clearly shewn that the main cause of the want of success lay in the subsoil water, which was found in some places at from 4 inches to 2 feet below the surface. To remedy this, the worst part of the farm, where absolutely nothing would grow, was broken up to a depth of 18 inches and drained at intervals of 6 feet with pipes running 4 feet below the surface.

The result of this was that an excellent crop of grass was obtained with extraordinary rapidity, and since that time no real difficulty has occurred. In other parts of the farm the less costly method of raising the surface above the subsoil water was adopted with the best results. At the present time (1891), this farm is one of the most remunerative.

As regards the crops, it was found at a comparatively early period that grasses did better than anything else, and that guinea grass gave the heaviest crop, but did not find a ready market, while it had the further disadvantage of requiring an occasional change of soil. On the whole, hurrialie proved the most satisfactory. It grows very readily and speedily, propagates itself by means of runners, affords an excellent food for horses and cattle, and makes a splendid hay. It commands a ready sale both as green fodder and dry, and will bear considerable extremes of drought and moisture. Later experience has given ample confirmation to these results, and at the present time (1891) no other crop is grown on the Municipal farms of Madras. Another important lesson was learned in the mode of laying out the beds, and experience has shown that sloped beds, over whose surface the sewage flows evenly by the force of its own gravity, give on the whole the best results, and are the most easily and economically managed.

At the present time the land under irrigation by the sewage of Madras amounts to 96·33 acres, and includes many private gardens. The liquid discharged on the land amounts to 3,558,000 gallons daily. In the estimate of land watered, the areas in the public parks and a private garden of about six acres are not included. Sewage is taken from the street cesspools of an undrained part of the town, and delivered free to the owner of the garden for the sake of disposing of it without polluting the Adyar River. About 42 iron single bullock carts, 25 sewage carts (holding double the quantity of the former), and 20 hand carts deposit sewage there morning and evening. The owner dilutes the sewage with well water, and uses it principally for irrigating cocoanut palms and plantains.

The Municipal farms consisting of 58 acres were put up to auction for a term of three years, commencing April 1891, and knocked down for Rs. 46,800, which is nearly Rs. 6,000 more than their total cost of maintenance for the past three years, but, owing to certain changes which had been made, the estimates for the present contract shew a profit, to the Municipality, of Rs. 12,553, and it will at the end be disposing of 4,500,000 gallons of sewage water daily.

The grass crops receive no sewage for 15 days before cutting, and when the Veterinary Department tested an aqueous infusion of the hay supplied to the Commissariat, it was perfectly sweet, and no odour of sewage could be detected. Both the grass and hay form excellent and nutritious fodder, and the horses relish it. Cocoanut palms are largely irrigated with sewage in private gardens, and chiefly used for toddy. Some of the Natives believe that if these trees are fed on sewage for a time and afterwards with water, they wither and die. Plantains do particularly well in sewage, and the fruit is of fine quality and very abundant. English root vegetables do well, and are good. Cabbages and other greens are not so good. Native vegetables, bandecai, brinjals, snake-root, &c., are not considered to be so palatable when grown in sewage as when irrigated with water. Still there is a considerable sale for them in Madras.

Religious scruples have never interfered with the disposal of sewage by the methods under consideration in Madras, and popular prejudice has been only such as would occur in the mind of any one unfamiliar with such matters, when presented for the first time with the idea of food being grown in sewage.

A good many people, Europeans as well as Natives, object to vegetables being manured with human nightsoil, but there is such an absence of prejudice on the part of some of the Native cultivators that they will take raw nightsoil, if they can get it, or remove it from the pits three or four months after it is buried, and before it has undergone those changes through which it becomes converted into a species of poudrette.

Some of the owners of gardens along the outfall channel are by caste Hindus, and use sewage for the irrigation of their gardens. In some instances burial and burning grounds are in close proximity to sewage farms.

Sewage Irrigation at Paris.

In the year 1869, which dates the commencement of the Madras experiment in sewage irrigation, the city of Paris purchased land at Gennevilliers to test the practicability of sewage farming. The work was stopped during the war, but taken up immediately afterwards, and the rate of progress may be inferred from the quantity of sewage put on the land. In 1876 it was 1,765,621 tons, in 1880 it rose to 15,000,000, and in 1884 it reached 22,493,922 tons, distributed over 616 hectares of land (1,520 acres). The daily average amount applied per acre is 40·56 tons, and the annual average of liquid used was equal to a rainfall of 144 inches equally distributed. The surplus water not required by the plants escapes by means of drain pipes laid 12 feet below the surface, and falls into the Seine in a perfectly pure state.

The population on the estate, which was 2,186 in 1869, numbered in 1885 a total of 3,245. The general mortality in 1865 was 32 per thousand. In 1876 it was 25, and in 1881 it was 22. No case of typhoid occurred during the epidemic in Paris of 1882, and not a single case of cholera during the epidemic of 1884.

The rental value of the land, which was formerly from £1-9-0 to £2-8-0 an acre, rose to £7-4-0 and £8-0-0, and its selling value reached from £160 to £192 per acre.

The plain of Gennevilliers was very poor land, with sand and gravel beneath a very thin crust of soil, and its present value is entirely due to the fertilising effect of sewage irrigation. The land is all or nearly all devoted to the culture of market produce, such as cabbage, artichokes, potatoes, asparagus, salads of various sorts, peas, carrots, beans, parsley, onions, beets, lucerne, grass, sundry vegetables, nursery stock, trees, and cereals. They carry off the first prizes at the horticultural exhibitions of Paris. Their taste is not affected by the sewage water, if it is not applied to the parts of the plant above ground. The sewage water, even in winter, never gets below 40 to 44° Fah. in temperature.

It is popularly supposed, both in India and in England, that solid excrements have the greatest fertilising value, and that the fluids may be neglected. There are also very diverse opinions regarding the amount of fæcal matter produced by one person.

The following Table, prepared by Mr. F. C. Krepp, gives the quantity produced by an average individual of all ages and of both sexes:—

TABLE XI.

		Per Day.	Per Annum.	
		Pounds.	Pounds.	Cube Feet.
I.—Average of the Estimates of Baron, Liebig, Mr. Lawes, Professors Hoffmann, Witt, Way, Thudichum, Boussingault, Stockhardt, Saussure, Macaire, and others.	Solids...	0·24	87·60	1·39
	Fluids...	1·95	711·75	11·29
		2·19	799·35	12·68
II.—Average of Adults, as per Report of 1857 on "Engrais des Villes" presented to the Chamber of Representatives of Belgium.	Solids...	0·332	121·18	1·92
	Fluids...	2·536	935·64	14·85
		2·868	1056·82	16·77
III.—Average of all ages, being a reduction of 30 per cent. on the preceding quantities of Adults, nearly corresponding with Estimate I.	Solids...	0·232	84·83	1·34
	Fluids...	1·775	654·95	10·39
		2·007	739·78	11·73
IV.—General Average, by Liernur, of excrements actually collected, allowing for waste by evacuations out of doors.	Solids...	0·24	87·6	1·40
	Fluids...	1·51	542·4	8·60
		1·75	630·0	10·00

Mr. Fawcus' experiments on Bengalee prisoners give an average bowel excretion of 12 ounces or ·75 lb., due to the large bulk of vegetable diet eaten by Hindus. This is confirmed by the observations of Dr. Hewlett in Bombay. The volume is principally due to the proportion of water it contains.

Fresh fæcal matter from healthy persons living on mixed diet has an acid reaction when unmixed with urine, and this it retains for a considerable time; it then becomes alkaline from ammonia. If free from urine, it usually decomposes slowly, and, in hot weather, often dries on the surface, and subsequently changes but little (in England) for some time. In India it is reduced to powder by the alternate action of sun and dew, and falls into the ground or is dispersed by the wind.

The urine when unmixed with fæcal matter also retains its natural acidity for a variable number of days, sometimes three or four, sometimes eight or ten, or even longer, and then becomes alkaline from ureal decomposition. When the fæces and urine are mixed, the formation of ammonium carbonate from ureal decomposition is much more rapid; the solid excreta seem to have the same sort of action as the bladder mucus, and the mixed excreta become alkaline in twenty-four hours, while the separate excreta are still acid. And, in its turn, the presence of the urine seems to aid the decomposition of the solid matter, or this may be perhaps from the effect of the liquid, as pure water seems to act almost as rapidly as urine in this respect. Pappenheim states that the absorption of oxygen by the fæces is greatly increased when urine is added. When the solid excreta and urine are left for two or three weeks, the mixture becomes usually extremely viscid, and this occurs, though to a less extent, when an equal quantity of pure water takes the place of the urine. The viscidity is prevented by carbolic acid.

When the solid excreta unmixed with urine begin to decompose, they give out very fœtid substances, which are, no doubt, organic; hydrogen sulphide is seldom detected, at any rate by the common plan of suspending paper soaked in lead solution above the decomposing mass. When heated, a large quantity of gas is disengaged, which is inflammable, and consists in great measure of carburetted hydrogen.

When (instead of being dry) urine is present, ammonia and fœtid organic matters are disengaged in large quantity. When water is also present, and if the temperature of the air is not too low, not only organic matters but gases are given out, consisting of light carburetted hydrogen, nitrogen, and carbon dioxide. Hydrogen sulphide can also be disengaged by heat, and is almost always found in the liquid, usually in combination with ammonia, from which it is sometimes liberated and then passes into the air.

Taking an average of the analyses of the various authorities quoted in Table XI., we find that the solid and fluid excrements of an average individual, of all nations, sexes, and ages, contain the following percentage of ingredients:—

TABLE XII.

Analysis of Excrements (Krepp).

Ingredients.	Fæces.	Urine.
Water	75·0	93·99
Organic substances	12·2	4·15
Nitrogen *	1·4	1·42
Phosphoric Acid †	1·06	0·24
Potash	0·29	0·20
Insoluble Silica	1·48	......
Oxide of Iron	0·54	......
Lime	1·72	......
Magnesia	1·55	......
Sulphuric Acid	4·27	......
Soda	0·31	......
Chloride of Sodium	0·18	......
Total...	100·00	100·00

* Nitrogen equal to ammonia—Fæces, 1·70; Urine, 1·73.

† Phosphoric Acid equal to Phosphate of Lime—Fæces, 2·30; Urine, 0·52.

The annual produce of an average individual of the four principal ingredients in the above Table are as follows:—

TABLE XIII.

	Fæces.	Urine.	Total.	Value.	
	Pounds.	Pounds.	Pounds.	s.	d.
Ammonia (Nitrogen)	1·49	9·38	10·87	7	3
Phosphate of Lime (Phosphoric Acid)	2·00	2·80	4·80	1	7
Potash	0·25	1·08	1·33	0	7
Organic substances	10·51	22·49	33·00	0	7
	14·25	35·75	50·00	10	0

The above estimate refers to the excrements actually collected, allowing for waste.

Mr. Krepp, from whose work the above figures are taken, adds that if human excreta, including urine, were reduced by evaporation to the dry condition of guano, they would contain by weight fully 20 per cent. of ammonia, in which respect the material compares very favourably with guano, which contains only 8½ per cent. The guano has, of course, suffered by long exposure to the sun before having been collected.

According to Macaire and Marcet, the manurial value of 1 lb. of human excrements is equal to 13 lbs. of that of the horse, and 6 lbs. of that of the cow.

Professor Voelecker has stated that the fertilising ingredients contained in the annual fæcal matter of an average head of population are capable of raising as much grain as 75 lbs. of Peruvian Guano. The application of 2½ cwt. of guano per acre gives, according to Professor Voelecker, an increase of 12 bushels of corn. The manure of one individual would thus yield an increase of 3·21 bushels or 189 lbs. of grain.

These figures refer to the quantity of produce that is to be obtained in addition to what the land would yield without the manure.

Speaking of the total amount of crop to be obtained from land under sewage manure, Mr. Krepp states, upon the authority of such men as Liebig, Boussingault, Saussure, Stockhardt, Macaire, and others, that ten shillings worth of pure fæcal matter can grow ten times its value in human food. And though, of course, only from one-fifth to one-sixth of the crop so raised is directly due to the manure, and the remaining four-fifths or five-sixths might have been raised without it, still the latter mode of culture could only be carried out for a certain limited period, when exhaustion of the soil would occur without fail. It may thus be asserted as a most valuable fact that £1 worth of human manure is capable of producing £10 worth of breadstuffs without in the least affecting the permanent fertility of the soil.

More than twenty-five years ago the official report of the municipal authorities of Groningen stated that the weekly removal of excreta, together with street cleaning, cost the town annually £2,500, while the sale of manure by public auction yielded £4,167, leaving thus a clear annual profit of £1,667 in a town of 37,000 inhabitants.

As the cesspits were not watertight, much of the urine was lost. The mean annual temperature of Groningen is 47° F., ranging from *means* of 63° to 31°, so that weekly removals of the contents of cesspits, in which ashes were doubtless mixed, was possible.

In India mixed fæcal matter begins to be offensive in an hour—which is tantamount to saying that it begins to lose some of its fertilising properties; therefore, for hygienic, as well as for economic reasons, it should be distributed in cultivated land within the least possible time after its production.

Although in various parts of India many experiments have been made in cultivation with dry and wet sewage manure, many of which are still in successful operation, information regarding the analyses of Indian nightsoil, of vegetable-feeding people, and of its manurial value per head per annum is very difficult to find. The scarcity of latrine and of urinal accommodation, the habits of the people, and the absence of coercion to prevent nuisances, all contribute to the loss of a very large part of the urine that should be collected with the fæces. Thus, until the police co-operate with the Health Officer and the Municipal Engineer, no city will realise the full value of its sewage as manure. This will come in time. A circular letter was issued, dated 10th March 1888, by the Under Secretary to the Government of India, Revenue and Agricultural Department, which resumes the results of experiments made with sewage manure in Bombay and in Madras; also the following:—

Mr. Burk's Report on sewage farming at Cawnpore in 1878, with the aid of Farakhabad Kachis.

Mr. J. H. Harrison's Report on the same in 1882.

Report on sewage cultivation at Nagpur, 1883-4.

Report on experiments made at Jeypore by Dr. Hendley, Civil Surgeon.

Details of the manufacture and sale of 730 cubic feet of Poudrette daily at Poona in 1880, by which the expenses for conservancy were reduced to Rs. 13,000 per annum.

Major Ducat's project of sewage irrigation for Poona and for Ahmedabad.

This circular letter contains much that is interesting in the general confirmation it gives to the value of nightsoil as manure, especially when associated with an ample water supply, which greatly assists the changes that must take place before the sewage can be assimilated by plants.

The Trenching of Nightsoil.

When properly carried out, the conversion of fresh nightsoil into manure by burying it in trenches is one of the best systems known in India for small communities. Wherever it has been tried, the manure finds a ready sale, and as all who wish may purchase it, the distribution of the refuse of a town is divided as much as possible in the neighbourhood. In agricultural economy it has less value than the application of the whole of the waste water and nightsoil of a town to one estate laid out expressly to receive it, but it serves to awaken the cultivator to the manurial value of a material which he has heretofore neglected or misused, and which is capable of increasing, more than anything else within his reach, the productiveness of his land. The soil for effective trenching should be loamy and porous, and fairly well drained, and the section and depth of the trench must be of such dimensions as shall allow the process to be carried out without nuisance.

The dimensions will vary with the quality of the soil. The temperature of the air and of the ground are favorable to the changes that take place during the process of conversion, and land that has been used for a period for trenching has its productiveness greatly increased.

Trenching is best suited for localities with a moderate rainfall, as the process of sewage removal will admit of no interruption.

At Nasick the nightsoil of the town containing 35,000 inhabitants is trenched in loamy soil in a manner that is both effective and profitable. The trenches are made about 18 inches wide and deep, and of any desired length. They receive twelve inches of sewage, and are then covered up with earth.

After a period of two to three weeks, the sewage is removed, with part of the earth which it has saturated, and placed in a depôt for sale. It has now no offensive smell, and is readily purchased and used by the cultivators of Nasick.

At Poona, with a population of 129,751, the nightsoil is collected in carts and trenched in the suburbs in a manner similar to that in vogue at Nasick. During the process of burying, it is mixed with ashes resulting from the burning of *cutchra*: these ashes are useful deodorisers, besides adding to the manurial value of the resulting poudrette, which is all sold and used in the vicinity of the town. Trenching, as carried out in Cawnpore, is one of the worst methods of disposing of sewage. The urine and fæcal matter from public latrines, and from depôts of nightsoil, carried by scavengers from private houses, is transported in small tank carts, of 12 cubic feet capacity, to pits dug in the suburbs of the town on cultivable land. The pits are about 20 feet square and 4 feet deep, and are filled up with the liquid nightsoil, which is left to heat up and ferment in the sun. The ground being of clay, there is very little combination between it and the sewage, which putrefies so freely as to be covered like beer with a head of foam, due to the gas bubbles rising through it. The stench is indescribable, and lasts at least two years. The residue, when dry, is sold to cultivators as poudrette, having lost the greater part of its fertilising powers in the gases of decomposition.

The trenching grounds are generally located to windward of the town, and near enough to be horribly offensive at times, and as cholera and typhoid fever are at home in Cawnpore, everything seems to have been done to render their sojourn permanent. By this method, the the town of Cawnpore obtains the smallest possible manurial value from its sewage, while the contagion of cholera and typhoid is kept working in a circle.

This method of disposing of nightsoil is doubtless one of the causes which have contributed to keep up the average death-rate of Cawnpore during ten recent years to 54 per thousand.

There is only one worse method than the one described above, and it is the system in vogue in Cairo. All nightsoil and sullage flows into a large covered cesspit below the houses. It is built at the bottom, and part of the way up, without mortar, so that the liquids which fall into it shall escape into a porous stratum on which the town stands. When the Nile rises, the stratum is filled with water, which in many parts of the towns rises to the surface, driving up the ground air and carrying up dilute sewage. This takes place during warm weather, and the rate of evaporation from the surface may be approximately estimated from the returns of street watering on the dry parts of the town. Two litres per square metre is the quantity per day distributed by the water carts, which is equal to 40·9 lbs. per 100 square feet of surface daily, or over four gallons. When the Nile falls, the spring level below the town descends, and the contents of the cesspits flow away and save the owners the cost of emptying. The foundations of the town are thus soaked with sewage, and wells cannot be sunk, or new foundations laid, without coming in contact with the sewage-polluted soil. There are, below the town, numbers of short tunnels with dead ends, built of open masonry, of the construction of which no record exists. They are used as cesspits, and are never emptied, unless they become clogged, or, as may sometimes happen, the surrounding soil becomes congested. This is indicated by the walls and floor of the lower storey of the house above them becoming damp, and not unfrequently by an outbreak of typhoid fever among the tenants of the house.

The cesspit has no ventilating pipe, and each discharge of water that enters displaces an equal volume of the foulest sewer gas which enters the house. There is an additional discharge due to the *breathing* of the cesspit, which takes place twice in twenty-four hours in correspondence with the fluctuation of barometric pressure (*see* Plate I.).

The cesspit system is common in Baroda and in Ahmedabad—only in these towns they must be emptied periodically; and although they may not be as bad as those of Cairo, they still contribute to the contamination of the subsoil and the wells, and in addition they defile the air in their immediate neighbourhood.

In Japan for centuries past the collection and disposal of nightsoil has been carried out in the following simple manner, as described by Mr. E. S. Morse in his work on "Japanese homes and their surroundings":—

"The receptacle in the privy consists of half a "petroleum oil barrel or a large earthen vessel sunk in the "ground, with convenient access to it from the outside. "This is emptied every few days by men who have their "regular routes; and as an illustration of the value of "this material for agricultural purpose, I was told that "in Hiroshima, in the renting of the poorer tenement "houses, if three persons occupied a room together, the "sewage paid the rent of one, and if five occupied the "same room, no rent was charged! Indeed, the immense "value and importance of this material is so great to the "Japanese farmer, who depends entirely on it for the "enrichment of his soil, that, in the country, privies for "travellers are always established by the side of the "road, in the shape of buckets or half barrels sunk in "the ground.

"In Tokio, a city of nearly a million of inhabitants, "the nightsoil is carried off daily to the farms outside "the city, the vessels used being long cylindrical "buckets, borne by men and horses. If sensitive persons "are offended by these conditions, they must admit that "the secret of sewage disposal has been effectually solved "by the Japanese for centuries, so that nothing goes to "waste. And of equal importance too is it, that of that "class of diseases which scourge our communities as a "result of our ineffectual efforts in disposing of sewage, "the Japanese happily know but little. In that country "there are no deep vaults with long accumulations "contaminating the ground, or underground pipes conducting sewage to shallow bays and inlets, there to "fester and vitiate the air, and spread sickness and "death. On the other hand, it must be admitted that "their water supply is very seriously affected by this "sewage being washed into rivers and wells from the "rice fields where it is deposited, and the scourge of "cholera, which almost yearly spreads its desolating "shadow over many of their Southern towns, is due to "the almost universal cultivation of land by irrigation "methods."

The system above described is only possible in a poor country where labour is very cheap, but the practical character of the Japanese people, and the favour which their Government has shown towards useful public works, renders it likely that the more objectionable features of their system of disposing of sewage will soon be remedied or minimised.

In India the bulk of the population lives in villages where labour is very cheap and money proportionately scarce. A modification of the Japanese system of removal of nightsoil might, through the agency of the *mehter* or sweeper caste, be adopted, by which the excreta deposited daily around the village might be collected and utilised on land in the near vicinity. The manurial value of nightsoil in Japan and in India must be equal, and although at first the *mehter* would have to collect it from the waste ground around the village, the profit from it would in the end make it pay him to construct and maintain rough latrines for the public use, such as exist in many towns.

As soon as the profit of the privilege became known, precautions and regulations could be introduced for improved management.

No other consideration than that of profit is likely to prevail, with the villager, in making him remove the filth which surrounds his dwelling with a zone of stenches, but, once learnt, the lesson in manuring is not likely to be forgotten.

The disposal of Solid Refuse by Burning.

The principal difference between the composition of the solid refuse of an English and an Indian town consists in the proportion of coal cinders and ashes in that of the former.

One hundred tons of London solid refuse or dust contains 81·4 tons of cinders and ashes mixed, of which 28·8 tons are cinders of the value of coke breeze (small coke).

The animal and vegetable refuse amounts to 14·2 tons, and the remaining 4·4 per cent. consists of broken pottery, bones, rags, old metal, and glass. This refuse contains on an average 29½ per cent. of water. The temperature of the flues of the furnaces in which this material was burnt at Whitechapel varied from 180° to 1000°, the average of eight cells or furnaces being 490°.

The proportion of cinders varies in different English towns with the season and the cost of coal. In the coal districts the proportion of combustible matter is greatest.

An exhaustive Report was prepared by Mr. S. Codrington, M. Inst. C. E., Engineering Inspector of the Local Government Board, upon the working of various furnaces for the destruction of solid refuse in twenty-four towns in 1888, from which (Report) the present data have been taken. The same class of refuse was burned in them all. The reduction of weight of material by burning varied from ¼ to ⅓, mostly clinker. The best result in cost of burning was 7*d.* per ton, but in many cases the heat of the furnaces was utilised for useful work.

At Warrington it was applied to the drying of pail contents, and at Southampton power for raising sewage effluent and sludge by Shone's ejectors is obtained entirely from the destructor, a large proportion of the heat being made available.

At Ealing a considerable proportion of the steam power is utilized in connexion with the sewage works. At Batley the heat from a destructor in course of erection would supply steam for a sewage pumping engine. At Nottingham the refuse raised steam for electric lighting. Generally speaking, although the escape of dust and fumes from the chimneys had not been entirely overcome in 1888, the report as to the ultimate success of burning town's refuse was favorable, and more recent experience has justified the expectations of Mr. Codrington.

The furnaces work day and night throughout the week, being banked on Saturday at noon, and re-worked at midnight on Sunday. The residue of vitreous clinker is useful for mixing with tar to form floors and footpaths, or for levelling up waste ground.

In Cairo and in Alexandria the combustible part of street sweepings and garden refuse is burned to heat the public Turkish Baths.

At Poona the ashes from Cutchra furnaces are used to mix with fresh nightsoil during the process of trenching, which is carried out at that town in a very effective manner. The resulting poudrette finds a ready sale among the local cultivators.

Indian solid refuse or *cutchra* contains no coal cinders, and is largely composed of stable bedding, horse dung, and vegetable refuse, mixed with street sweepings, kitchen refuse, old glass, metals, &c. During the monsoon it is generally very wet and soft, and for this reason alone it is unfit to be burned in any furnace designed for such material as the English refuse is composed of. Wet vegetable refuse lies so close that air cannot penetrate it to support combustion, and unless special means are employed to burn it, devised for the nature of the fuel it contains, no satisfactory results may reasonably be expected.

The disposal of the solid refuse of Bombay may be considered as a type of the work to be done in a large Indian city. Bombay produces 384 tons of Cutchra daily, or 960 loads of 8 cwts. The weight of the material is 42 lbs. per cubic foot. Bombay produces 172 tons of Cutchra per 1,000 of population per annum, as against 250 tons per 1,000 of the population of large English towns. The weight of the latter is 56·5 lbs. per cubic foot.

Various attempts have been made to dispose economically of the 140,000 tons of Cutchra produced annually in Bombay. It has been carried by train to the north of the Island, and also used for levelling up low-lying ground; it has been carted and deposited in great quantities in marshy ground in and near the town, and it has been burnt in furnaces of various types and sizes. A furnace of the "Beehive" type, invented by the borough engineer of Burnley, was tried, but being designed for harder and drier refuse, it did not suit Bombay refuse. Next, a furnace was built with two ranges of firebars, with a total area of 70 square feet. The chimney had an area of one square foot, and a height of 60 feet. When both fires were lighted, the lower fire burned the air that should have fed the upper one, and caused a discharge of dense smoke, which could not escape, the chimney being much too small for such a surface of grate. This furnace, after a few trials, was abandoned. From experiments made by the author on wet stable litter, he found that by drying it in the sun it lost 60 per cent. of moisture, and when afterwards burned in a boiler furnace it was found to be equal to one-eighth of its weight in coal.

There are times when much of the Cutchra is as dry as the sun can make it, but if it is to be treated successfully, it must be dealt with when it contains as much as 60 per cent. of water, besides a certain proportion of earthy incombustible matter. One pound of dry Cutchra, mixed with 1½ lbs. of water, may be taken to represent the average material to be dealt with in wet weather.

We have now to deal with the following factors:—

1 lb. Cutchra, Calorific value $\frac{13000}{8} = 1625$ Units.

Temperature of materials, 80° F.

Specific heat of Cutchra, ·570.

1½ lbs. of Water at 80°.

Weight of air at 80° = ·0733 per c. f.

Specific heat of do. ·2379.

The fuel needs 1 cubic foot of air for every 44 Units of heat produced. $\frac{1625}{44} = 37$ c. f. $= 2{\cdot}71$ lbs.

The temperature in the flue, in order to maintain good combustion, should not be less than 480° F.

Then 1 lb. of Cutchra gives		1625 Units.
Add temperature of fuel = 80° × ·570 =		46
		1671
The water will absorb heat to raise it to 480°, amounting to 480°—80 × 1·5 =	600 U.	
The air will absorb 2·71 × 400 × ·2379	257	
Radiation from furnace at 12°	195	
		1052
leaving a balance of		619 Units

per pound of wet Cutchra burnt.

If half the water were removed by rollers before burning, as is sometimes done with tanners' bark in England, the case would stand thus:—

1 lb. Cutchra		1671 Units.
¾ lb. Water absorbs	300 Units.	
2·71 lb. air will absorb	257	
Radiation	195	
		752
Balance of surplus heat		919 Units

per pound of Cutchra burnt.

If the Cutchra is dry 1 lb. gives		1671 Units.
Deduct for air	257	
,, for Radiation	195	
		452
Balance of surplus heat		1219 Units,

which is about ⅛th of the heat of coal under similar circumstances.

These figures are all based on the assumption that stoking and combustion are carried on *at the same rate*, and that no great fluctuations of heat take place, which would cause smells from unburnt gases. It is the primary object of the furnace that these gases shall be consumed as completely as possible, otherwise it is merely an exchange of nuisances. One-eighth of the effect of good coal appears to be the greatest possible result obtainable during dry weather from Cutchra, and eight tons have to be handled instead of one ton of coal. Its cost is, however, only that of collection, and where coal and wood are dear, and waste land for discharge at a considerable distance, it may be burnt with advantage.

Cutchra is reduced by burning to $\frac{1}{10}$th of its original weight, and becomes a useful deodoriser for mixing with noxious materials that cannot be treated in the furnace. Forty tons are burnt daily in Bombay during the fine weather.

Screened or selected refuse is burned under boilers at Manchester, Bolton, Glasgow, Birmingham, and other towns. At Birmingham it is burnt on moving firebars in a grate 5 ft. wide and 5 ft. 6 ins. long, which, when working, moves the clinker gradually to the back, where it falls into the ashpit. The refuse burnt is principally coal cinders, and as the bars move it steadily through the furnace, complete combustion is obtained. Much of the Bombay Cutchra might be burnt during dry weather in a suitably constructed boiler furnace and used to raise steam for pumping sewage. In order to be properly burnt, the grate should be large, and the feeding should be continuous, like that of straw-burning furnaces. The feeding must be so done as to deliver the fuel in a uniform layer over the whole width of the bars, and the thickness of the layer must be such that it shall not crush itself and exclude the air. In this manner the maximum quantity will be burned in the furnace.

The best duty in pounds of rubbish burnt on a square foot of furnace at the Glasgow Crawford St. Works was 39·31 pounds. The average was 20·8 lbs. per hour. Each furnace had an area of 84 square feet of bars, and burnt 17·5 tons per day. If two-thirds of the Bombay *cutchra* were burnt at the Glasgow rate, then $\frac{384\times2}{3} \div 17{\cdot}5 = 15$ similar furnaces would be required to dispose of the whole.

Whatever may be the proportion of rubbish burnt, the value of the residue must be taken into account as a deodoriser. It must always be understood that municipalities are compelled to remove and dispose of a certain quantity of *cutchra* per annum, and that the work of removal has to go on daily. Until they discover a means of making a profit out of it, they must continue to study the best means of reducing their loss in the expense of collecton and removal. If the loss on burning should prove less than the loss on removal by carts to waste ground, there is an advantage in burning. It may thus pay a municipality to burn material that could not be used as fuel with any advantage by any private firm or public company.

The disposal of solid town refuse upon waste lands, or for levelling up hollow or low-lying places, is the simplest and cheapest of all methods, if the cost of handling and transport are not excessive, provided always that land is available, and that no nuisance results to the inhabitants of the suburbs.

The cost of transport and handling are much influenced by the state of the roads leading to the place of deposit, and the appliances used for moving the material. When carts are used to carry it to the point of discharge, the duty of the cattle may be reduced to two-thirds by soft dusty surfaces in dry weather, and to less than one-half in wet weather. Carting, with bullock traction, of worthless and possibly noxious material, can only be done with advantage on well-paved roads and for moderate distances. Over unpaved ground it should be carried on rails upon suitable wagons. A horse or other draught animal can draw 6⅔ times as much weight upon a level tramway as upon soft ground at 3 miles an hour, and if occasional rising grades occur on a tram line, spare animals may be kept to assist, either in team, or by dividing the load. Much handling of the material may be avoided in a city by making the cart bodies removable, so as to be transferred to the frames of the tram wagon. A cubic yard of capacity is found, in India, to be a convenient size for a dust cart. This size might be adopted with a square base, which would allow the box to be fixed in any position on the tram wagon body. The box should be of sheet steel, and a certain number might be provided with lids. The load would be 8 cwt. to 10 cwt.

The boxes, in the first place, would be collecting receptacles, resting on platforms of such a height as to allow them to be easily drawn on to the cart frame and locked. The platform would accommodate two boxes, so that the cart might deposit an empty one before taking a loaded box. The carts would deliver their bodies at the tramway siding or terminus, where they would be transferred by a light crane to the wagon frames, each of which might carry three boxes. A similar light crane, of half-ton capacity, fixed to a post on a flat wagon, would lift them by trunnions, at the place of discharge, off the wagon bodies, and swing them to the position of discharge to right, front, or left of the rails.

In this manner the Cutchra might be deposited with the minimum amount of manipulation, the lifting of the boxes at either end of the tramway being limited at most to three inches.

Where large quantities have to be removed daily, steam or electric traction should be used, with larger wagons holding six or eight boxes. The same system of loading and unloading would be used. The washing of the boxes could be effected at the town depôt of the line while they were being transferred from wagons to carts. A jet of water spray would be used while the box was suspended from the crane, mouth downwards, to wash the interior and exterior of each box before returning to some platform in the town.

The changes that take place in made ground, due to the decomposition of organic matter, seem to require, in India at least, a good deal of study. Made ground has the reputation of being very unwholesome as a place of residence for an indefinite number of years. If composed of a large proportion of vegetable matter, it is certainly unsafe to build any but the lightest structures upon it until it has settled. But its insanitary influence must not be based on any European traditions, as it is subject to influences that are not known in Europe. The influence of warm and copious rain, high ground temperature, rapid decomposition, aëration due to the porosity of the material, and the influence of barometric fluctuations of pressure, and lastly the labours of the ants, which multiply in incredible numbers in Cutchra, all tend to reduce made ground to wholesome conditions more rapidly in India than in colder lands. The period at which made ground may become safely habitable has a very important financial bearing for municipalities; in the interval, cultivation, with sewage irrigation as at Madras, would seem to provide the best use for it.

The details of construction of such a plant as would be required for this work must be designed with the greatest care, for all similar parts must be interchangeable. Much remains still to be done to improve the designs of municipal carts, particularly with respect to wheels and axles. It may justly be said that no thoroughly good type of wheel and axle exists at present. The best wooden wheels are necessarily heavy, in order that their joints may last under the great fluctuations of temperature and moisture in the air, which, by swelling and shrinking the wood alternately, produce a deterioration which is quite independent of wear. Another cause of the rapid deterioration of wheels is the scarcity of well-seasoned timber. Dealers will not keep their stocks to season, and very few cart builders have sufficient capital for the purpose.

Steel and iron are the best materials for the wheels of all vehicles in India, as they are practically unaffected by heat and moisture, but so far no pattern has yet been produced that is cheap enough or durable enough to supersede well-made wooden wheels. Some have been too heavy, most have been too dear, and nearly all have had a fatal weakness in the attachment of the spokes, which, being fastened by a screw at one end, would either work loose or break at the thread.

It would pay any one of the large Indian Municipalities to advertise in Europe, America, and Australia for a good metallic wheel and axle. The prospective demand in India for a really good metallic wheel would be well worth the attention of the largest manufacturers. Railways have long since found a great economy in reducing the parts of their rolling stock to standard sizes, so as to expedite repairs and work with the minimum number of locomotives and wagons. Municipal plant is well suited to the application of the same system. The stores of the municipality or of the contractor who does the repairing should have stock of all the spare pieces likely to be required, so that when any tool, vehicle or apparatus arrives for repair, there should be no delay for *making* anything, but only for the exchange of new for old parts. The quantity of stock necessary for the repair of say 20 carts annually will not vary much from one municipality to another, provided the parts are of the same quality.

The sight of a number of dust, nightsoil, or water carts standing for days or weeks awaiting repair, argues, as a rule, a serious want of system in stores and workshops.

CHAPTER VIII.

VENTILATION OF DWELLINGS.

In spite of the number of doors and windows to be found in houses in India, bad ventilation is one of the great defects of dwellings, both of Natives and of Europeans. It must be charged with much of the unnecessary sickness that falls to the lot of dwellers in hot climates.

Ventilation may be described as a method of supplying an amount of air, sufficient to meet the requirements of the lungs, and to carry off the emanations and surplus heat from the body in a regular manner. The human lungs require to be supplied through the longest lifetimes, and without intermission, with a steady and regular amount of pure air. If the air is impure, the function of the lungs is impaired, and the system suffers by deterioration; if the supply is stopped for only a few minutes, death ensues.

The mean temperature of the human body is 98·4° Fah., but the combustion of our food produces much more than the necessary quantity of heat to maintain that temperature, so the surplus must escape by radiation and by evaporation. The conditions of our animal economy require that the temperature of the blood shall not vary by more than three-quarters of one degree, whether we live in the Tropics or in the Arctic regions, and if anything occurs to interfere with the function of the skin, an immediate rise in temperature is the result.

What oppresses us in hot weather is not the heat of the air which penetrates and accumulates in our bodies, but our *animal heat*, which, escaping less freely on account of the hot atmosphere around it, accumulates and produces a sense of exhaustion.

The temperature of the air in the interior of India is frequently much above that of the blood, and when this is the case, evaporation from the skin keeps the temperature of the blood within healthy limits.

Box, in his "Treatise on Heat," says that an ordinary man developes heat at the rate of .84 units per hour by the combustion of his food. The heat thus produced serves to keep up the temperature of the body. If there were no means to prevent its accumulation, the temperature would rise without limit, but such means are provided, and are so nicely adjusted, that the body is maintained uniformly at about 98·4° under all circumstances. The surplus heat is carried off—1st, by radiation to cold walls or other surrounding objects; 2nd, by contact of cold air; and 3rd, by perspiration, in which the fluids of the body are vaporized, and heat becomes latent. With moderate temperatures all three of these means are in operation, and only then is perfect comfort experienced. In extreme cold, perspiration is nearly suppressed, and all the heat is carried off by radiation and the contact of cold air. When the temperature becomes moderate, insensible perspiration ensues, and the skin becomes moist; as the temperature rises, the amount vaporized becomes progressively greater, and when the air and surrounding walls have attained the temperature of 98·4°, the loss of heat by radiation and contact of air is suppressed, and the whole of the animal heat has to be carried off by perspiration, which then becomes excessive and takes the form of sweating.

In considering the amount of air required for ventilation, we must be guided by the several offices which that air has to fulfil. They are 5 in number:—

1. To supply the organs of respiration with the necessary amount of oxygen.
2. To carry off the vapour given out by the lungs and the body.
3. To dilute and carry off the natural exhalations from the skin.
4. To carry off the animal heat not absorbed by radiation and evaporation.
5. To supply the lighting apparatus.

The same air may possibly perform several of these offices simultaneously or consecutively.

An ordinary man by breathing vitiates 22 cubic feet of air per hour.

To carry away the 284 units of heat given off per hour by the body when the temperature of the air is equal to that of the blood, ·263 lbs. of vapour would have to be evaporated per hour, and this would have to be distributed in a certain quantity of air, so as not to raise the relative humidity too high. Allowing an increase of 10 per cent., and assuming the saturation of the air to be 50 per cent. at starting, we find by reference to Table VII. that air at, say, 102° F., when half saturated, will carry 1·60 lbs. of water per 1,000 cubic feet. One-fifth of this quantity would raise the saturation 10 per cent., so to dispose of ·263 lbs. of vapour of water as above indicated the amount of air required would be $\frac{\cdot 236 \times 1000}{\cdot 320} = 822$ cubic feet.

The amount of air necessary to dilute, and carry off the natural exhalation from the skin, varies with the character of the individual as to health and personal cleanliness. At a temperature of 62°, 350 cubic feet is considered by good authorities in England an ample allowance per hour for healthy individuals, but in hospitals Peclet gives 2,000 and Morin 2,500 cubic feet per head per hour as the allowance for ordinary cases, and the latter recommends as much as 5,300 cubic feet in times of epidemic.

The air consumed, and the heat produced, by artificial lighting, next demand attention. Sixty cubic feet per hour is the amount of air estimated by Box to be contaminated by one gas burner, consuming 5 cubic feet of gas and producing light equal to 16 sperm candles. The heat given off from coal gas is equal to 696 units per cubic foot. Five feet per hour would therefore produce 3,480 units, which are capable of raising 18,749 cubic feet 10 degrees in the same time.

As gas usually burns overhead, the heated air rises to the top of the room, but if not allowed to escape, it will accumulate and finally interfere with the escape of animal heat from the persons below. Taking 98° Fah. as the normal temperature of the air, it is thus raised to 108° by a single gas jet.

The same amount of light might be obtained from kerosine with considerable economy of heat, as shown by the following Table :—

TABLE XIV.

Shewing the amount of heat produced by various illuminating materials while giving a light equal to 12 Standard Candles during ten minutes.

Tallow	100	Units of heat.
Spermaceti	82	,,
Wax	82	,,
Paraffine Wax	66	,,
Coal Gas	47	,,
Cannel Gas	32	,,
Petroleum	29	,,

In this table, Petroleum, or kerosine, is shewn to give only a little more than one-fourth of the heat (for a given quantity of light) produced by Tallow Candles. This is doubtless due largely to the superior construction of the wick. The Coal Gas is supposed to be burnt by an ordinary batswing burner. Kerosine, as compared with Coal Gas, is 38 per cent. cooler, and as it is the cheapest illuminant in India, it is in every way the best for private use. The Electric light being so rarely applicable need not be considered.

An ordinary burner like that of a street gas lamp, consuming five cubic feet per hour, produces 696 units of heat per cubic foot. This will suffice to raise 36,915 cubic feet of air 10 degrees in temperature, but as gas is rarely used in private houses even in Indian towns, where it is manufactured, we may take kerosine as the basis of calculation. Kerosine producing 62 per cent. of the heat of gas will therefore heat 22,887 cubic feet of air 10 degrees.

From the foregoing particulars it will be evident that the work of ventilation in India on account of difference of temperature of the air alone is totally different from that in England.

An increase of 20° of temperature at a place of public meeting is a matter of common occurrence, accompanied generally with considerable deterioration of the air. In India when the temperature approaches 90°, *two degrees* of increment makes a sensible difference in comfort, unless the air is dry.

Returning to our figures—

	cubic feet.
Respiration require per hour	22
Evaporation, when the temperature of the air is equal to that of the blood ...	822
Emanations from the body at least ...	350

The quantity, 822 cubic feet, of air required to receive the heat and vapour from the body, without raising the saturation more than 10 per cent., would make a reduction of reading on the wet bulb thermometer of 4 degrees. This quantity of air will include the 22 feet required for respiration, and the 350 for emanations. It may therefore be taken as the least quantity of air that should be supplied in a clean chamber per hour to healthy persons.

Sixty cubic feet per hour per burner is considered a good allowance in England for lighting, the walls of the chamber being supposed to absorb the surplus heat. This is true during the greater part of the year.

In India powerful illumination indoors, except for a short period of the night, is the exception rather than the rule: it is usually accompanied by the use of punkahs which agitate, although they do not renew the air, but which assist in a marked degree the escape of animal heat.

Powerful illumination indoors is employed on the occasion of social meetings, when an unusual number of people are together, and although the period of duration of the meeting may not exceed two hours, the heat developed by the lighting will be many times greater than that given off by individuals. An allowance must therefore be made for the heat of lighting, which will naturally include that required for combustion. Many circumstances combine to modify the estimate when all is considered, including the fact that 90° is a much more usual hot night temperature than 98°. An empirical quantity of 5,000 cubic feet may be taken per person as the allowance for lighting, which includes the smaller allowance of 822 cubic feet for evaporation.

So the ordinary allowance of air may be rated at 822 cubic feet, which must be increased, when strong artificial light is used, to 5,000 cubic feet.

The customary definition of a draught of air is a current calculated to produce discomfort and colds. The velocity of such a current depends largely upon its temperature. At temperatures ranging from 55° to 70° the velocity may be from 2½ to 3½ feet per second, but with temperatures over 80°, as much as 6 feet per second or 4 miles an hour may be used with safety.

It must always be remembered, with regard to ventilating currents, that if they cool one part of the human body much more than the rest, a cold will very probably be the result. A current that would only be refreshing if applied to the whole of the body may bring on cold and fever if it acts only on one part. This is frequently illustrated among people who sleep on a warm mattress under a punkah. The mattress being a non-conductor of heat accumulates the heat that should escape from that part of the body which lies against it, while the punkah keeps up a current equal to 4 or 6 feet per second above it. The sleeper, thinly clad, will turn over, exposing his heated side, with clothing wet by perspiration, to the current of the punkah, and, by the rapid evaporation of the moisture, receives a chill that may result in the gravest consequences. One of the most important uses of a bed is to regulate the escape of our animal heat, as our clothing does in the daytime. The heat should escape equally on all sides, so that the sleeper shall never feel hotter on one side than on another. This can be done by regulating the quantity of bedding beneath him according to the season, until he feels that the heat escapes equally all round. He is then much less likely to catch cold in a current of air than before, as his body will cool equally all round.

One of the best beds for use in hot climates has a web of woven rattan cane like the seat of a chair. The canework should be so slack as to dip at least two inches at the middle all along its length. The slackness takes much of the strain off the cane and makes the bed soft, even if it has only a single sheet upon it. Rugs or blankets may be added to suit any weather.

Those who sleep much out of doors should carefully observe by means of the maximum and minimum thermometer the fluctuation of temperature that takes place during the night. At certain times and places cool winds may begin to blow in the early morning after an evening of great heat, or in very dry weather with a clear sky radiation may cool the ground and the air many degrees below the day temperature.

Persons who sleep very soundly may not observe the change, and may not suspect the cause of the cold or the fever they may have caught by exposure with insufficient covering. Punkahs, when they cool only one part or side of the body, may easily produce cold.

Punkahs.

The literature of Punkahs refers principally to inventions for pulling them with a view either to economise manual labour or to supersede it. This is a subject that hardly concerns the present work, but as the swinging punkah itself is not likely to be entirely superseded by any other device for agitating the air, a few remarks on its construction may be welcome to the reader.

There are two fundamental propositions applicable to all swinging punkahs, which must always be remembered in making them—

1. All punkahs, when swinging at the same rate of movement, put in motion the same amount of air for every square foot of surface they contain.

2. The difference between the useful effect of punkahs lies in the quantity of air that is agitated *beneath* them.

These propositions require for the non-scientific reader a little explanation. The rate of movement is the number of feet per minute the punkah travels through the air. The length of a pull of the rope may be measured for an approximate estimate, but the real distance is ascertained by measuring in feet the travel of the middle of the punkah, *i.e.*, half-way down, and multiplying it by twice the number of pulls per minute. This gives the number of feet per minute through which the punkah travels.

In the second proposition, it must be noted, that all punkahs produce some current above them; the worst exert just one-half of their useful effect above them, and the best only a small amount which has never been measured. The worst punkahs are those with very long suspension cords hanging in churches and in lofty buildings. The panel or curtain travels very slowly, and hangs vertically, so that, presenting a surface at right angles to the direction of movement, the air divides before it, one-half going up, and the other down. All punkahs travel at the rate determined by the length of their suspending cords; they may be pulled rapidly forward, but they return at a velocity regulated by the law of gravity.

In all questions of dynamics, we must work according to the available power, and as the punkah-walla is, in the present instance, the motor, the work must be made to fit him. Repeated experiments have shewn that twenty-five pulls per minute represent the economical speed of working of an average coolie, so all suspended punkahs should work at this rate, however high the roof may be from which they are hung.

The rate of movement of a punkah is based on the law of the pendulum modified by the resistance of the air upon the curtain, and as the depth of curtain may vary, no fixed rule can be given for the exact length of the suspending cords.

The simplest way of finding the length of the suspending cords is to hang the punkah temporarily with cords going over the hooks and fixed within reach, or held by hand. The length may then be altered until the right speed is found. Ceilings up to 16 feet high will give a fair approximate length to punkahs, which must be hung six feet clear off the floor. Twenty-five pulls of 3 feet will give a speed of 150 feet per minute to the punkah bar. The pull should be in a downward and not in a horizontal direction. The downward pull being the easiest, the man can exert the greatest force in that direction, and to make the work as easy as possible, the swing-bar should be made heavy enough to lift the arm of the puller during the return movement. The bar of a small punkah should therefore be heavier per foot in length than that of a large one.

There is a vicious habit in punkah-pulling that should always be discouraged. It consists in arresting the movement of the bar before it reaches its full stroke, and causing the curtain to make a flap at each pull. By a popular error an improved current is ascribed to this trick of pulling which only decreases the useful effect of the punkah and wastes part of the work of the punkah-walla.

The variety that may be observed in the form of punkahs shows how diverse are opinions as to the best type.

At a lecture given by the author at the Sassoon Institute, Bombay, in 1888, six common types of punkahs, all of the same size, were tested under exactly the same conditions above a very delicate indicator that looked like a very large piano keyboard. The curtains were all twenty-two inches deep. The "keys" of the indicator were one foot long and four inches wide, and were delicately balanced on levers three feet long. The balance weights were hung in vessels of water to correct spasmodic movements. The ends of the keys carried disks of light cardboard four inches in diameter which formed a row facing the audience. The disks formed themselves into waving lines during the experiments, and shewed the difference of effect of the punkahs. The punkahs were pulled by a falling weight of two pounds which was *lifted* by the punkah-walla, so that the pulling could not vary in force, and all the punkahs were tested with the same length of suspending cord.

The panel punkah was found to have the least effect, and a piece of cotton dungri cloth with a light wooden rod attached to its lower edge produced a better downward current than any of the others.

A punkah curtain is a ship's sail reversed. It is drawn through the air in order to produce a current in a certain desired direction. It must curve or "belly" as the sail does, in order to facilitate the movement of the air, and the rod at the lower edge must be of such a weight as to produce a curve on the curtain like that of the blade of a revolving fan. The curtain should be perfectly plain, and of the thinnest possible material, such as muslin or fine silk, and the suspending cord should never exceed $\frac{1}{4}$ of an inch in thickness. Lightness in appearance should always be the object of the designer. Round bar iron, $1\frac{1}{4}''$ in diameter, covered with leather or leather cloth, makes a very effective swing bar with polished hard wood ends. When hung with 3-inch iron rings on the suspending hooks, the rubbing is transformed into a rolling motion and the punkah is noiseless.

If the roof of a room be too high for the proper swinging of punkahs, they may be hung in the ordinary manner, and the centre of suspension may afterwards be altered by attaching a light bar of wood across the suspension cords, horizontally, but at such a height from the swing bar as to give the right length for speed of movement. This bar is next fixed by thin wires to opposite ends of the room so that it cannot swing; it thus becomes the true centre of suspension of the punkah, which will then work with about 25 pulls per minute. Good silent pulleys should always be used for every change of direction of the pulling cord. It is a pity that punkahs, however badly made, will always produce some effect. The result is that they are usually the outcome of the individual taste of some Native carpenter, rather than a simple application of the most familiar Natural Law.

Many punkahs are at work which produce little more than half their proper effect, with a proportionate waste of food and muscle on the part of the puller. The power to propel one square foot of punkah curtain at the rate of 150 feet *per minute* is 27·17 pound raised one foot. A punkah, 6 feet long and 22 inches deep, would therefore require a force equal to 300 lbs., falling one foot per minute, and if run for 8 hours, the power, without any allowance for loss by friction, would have to be equal to 42·8 cwt., falling 30 feet during eight hours. The force is very small reckoned in horse power, being only $\frac{1}{110}$th of one H. P. per minute, but to store it by means of falling weights or springs would need a very costly and cumbrous apparatus.

Along the coast of India, where the air in warm weather is always damp, houses may, with advantage, be kept open all the day. Excluding part of the sun's light keeps down the temperature to a certain amount, but no practicable means are available for cooling the air, that is to say, lowering the temperature.

The temperature never reaches the intensity of the climate of the interior, and a steady current either from the wind or from a punkah removes the animal heat of the body at a satisfactory rate.

In the interior, the high temperature and the dryness of the air render it necessary to shut out the greater part of the light, and to stop the free circulation of the air in order to keep down the temperature within a house. In the evening, as soon as the temperature of the outer air falls to that of the air within, the doors are opened and circulation from without established. The building itself has, however, been absorbing heat from the sun all day, and at night it radiates, both into space and into the rooms; so that, although it is cooler indoors during the day, it is hotter indoors than without during the night. The house practically produces a rough average of the day and night temperatures. If the walls were made sufficiently thick and the circulation of air were stopped, a true average temperature would be the result.

The use of punkahs in a closed inhabited room facilitates the escape of animal heat from the body, but as they only agitate without renewing the air, there is a gradual increase of impurity from the time the room is closed until it is opened. When long continued, this practice must be injurious to the health.

The *kuskus* screen is a means of cooling and moistening hot dry day, in common use in India. When placed against a doorway on the windward side of a house, and constantly wet, a great reduction of temperature takes place in the air which passes through.

The Thermantidote is an elaboration of the *kuskus* screen or *tatty*. A ventilating fan is combined with the screen and a small pump, so that air is drawn into the fan through the wet screen and blown into the house, cooled and moistened. The Thermantidote being only used during one part of the year is frequently left in a corner—often exposed to the sun and the rain—until needed again. It is driven when out of adjustment, and usually gives a much smaller result for the power employed to drive it than the punkah. It is too complicated for the class of men who have charge of it. The fan wheel should be of such a diameter as to drive direct from its own axle without the belt or tooth gearing that gives so much trouble. Many charges are laid against the Thermantidote, of injury to the health of those who use it—or who, properly speaking, abuse it. No note is taken of the amount of humidity or difference of temperature of the air it discharges, nor of the velocity of the current.

The air from the Thermantidote is often as cool and as damp as the wind during the monsoon, and coming from a small opening and at a high velocity into a room, it is very liable to produce those chills, on the side of the person nearest to it, that result in rheumatic and other affections. The Thermantidote should never be used without a good Hygrometer and without strict attention to the temperature and humidity of the air discharged from it. Changes of climate, such as this apparatus produces so suddenly, cannot be borne by many people with impunity. All excessive changes should therefore be avoided. A large volume of air with moderate reduction of temperature and moderate increase of humidity is far safer than a smaller but colder and damper volume.

A well laid and pointed brick floor provides a large evaporating surface for cooling the air. Its action is uniform throughout the room, and clean burnt brick seems to possess certain advantages over *kuskus* as an evaporating surface in not being liable to decay. The following results were obtained by the author at Cawnpore in July 1891 in an office 27 ft. by 17 ft. paved with brick. At 7-0 A.M. 7½ gallons of water were put on the floor by the Bhisti, which was all absorbed in a short time, and, during the rest of the day, continued to evaporate into the air of the office. Two punkahs were kept swinging during the hours of business, and the doors, none of which were tight, were frequently opened and shut.

There were four persons in the room, and at no time was there any perceptible odour of imperfect ventilation.

Two Hygrometers were used, one on the verandah, and one in the office. The time of observation was 2 P.M.

	Dry Bulb.	Wet Bulb.	Hum. of Air.
On verandah ...	103°F.	89°	56 °/o
In office	88°	85°	87 °/o
Difference ...	15°	4°	31 °/o

A reduction of 15 degrees below the shade temperature in the verandah was thus obtained, with an increase of 31 per cent. of humidity. The experiment was continued during the dry hot weather of a whole year with considerable comfort, and no apparent ill-effects on any one. Had thesame work been done by a Thermantidote, the rapid current and excess of moisture that the air would have possessed, on leaving the apparatus, would probably have injured the person who sat nearest to it.

Air may be cooled without the addition of moisture by passing it through a flat metallic tube of sufficient length, and covered with coarse cloth which must be kept constantly wet. The tube must be in the shade with a free circulation of air about it. If vertical, the water supply may be at the top, and adjusted so as not to drip at the foot. If horizontal, the tube must be set on edge so as to have the two broad sides vertical. A narrow trough of water should lie along the top of the tube, supplying water to the evaporating cloth by means of wicks. Sheet copper is the best material for the tube, but sheet zinc will serve, and is much less costly. A fan at the end of the tube will blow the air through.

This apparatus is only useful in a dry atmosphere when evaporation is active, and a cubic foot of air cooled in this manner is much more effective than if the reduction of temperatrue had been effected by increasing the saturation. This method of cooling is similar to the cooling of water in a zinc bottle with a wet jacket.

The action of still air in cooling the body is somewhat complex. The heat, as has been stated (p. 177), may escape by evaporation entirely, when the temperature of the air is above that of the blood, or by radiation almost entirely when the temperature is very low. At the higher temperature the vapour escaping from the skin forms an envelope around the body, which, although lighter than the adjoining atmosphere, does not rise rapidly enough to suit the rate at which heat is produced. It acts like clouds at night, which, by impeding the terrestrial radiation into space, makes the night warmer.

If the movement of the vaporous envelope surrounding the body be accelerated by a current of air, the loss of heat is increased and a sense of coolness is the result.

Wherever the air is cooler or hotter than the surrounding air, a current downward or upward will follow. The rapid upward current, above a lamp chimney, may be observed by puffing smoke into it, and the downward current around a tall glass of iced water may be observed in the same manner.

If a syphon be constructed of sheet iron stove piping, one leg being whitewashed and the other painted a dead-black, it will, on being exposed in a vertical position to the sun, produce a current, due to the difference of temperature of the two legs. This is owing to the different rate of absorption of heat of different colours when exposed to the sun (p. 192). If the syphon be held with the openings upwards, the current will be upwards in the black leg, and downwards in the white leg; the air in the latter will have the shade temperature, while in the former it will have an increased temperature, due to the absorbing power of a black surface in the sun.

If the syphon be inverted, the current will still be upward in the black leg, and downward in the white one, but the velocity will be reduced, as the air must pass hot into the white tube, and can only escape at a rate proportionate to the heat it *loses* while descending. It will not lose all its heat for reasons which will presently be evident, so the velocity of the current will be retarded, because the difference of temperature of the air in the legs is less while the openings are below than when they are above.

The colour of any object exposed to the sun's direct rays has a most important influence on its rate of absorption of heat, and is of the greatest importance in questions of ventilation.

The annexed tables from experiments by Von Harlinger will demonstrate how much more difference of colour, rather than difference of material, influences the absorption of heat from the sun.

TABLE XV.

Of absorption of the sun's heat in cotton shirtings due to variety of "colours."

White	100	Turkey Red	165
Pale Yellow	102	Dark Green	168
Strong Yellow ...	140	Light Blue	198
Light Green	155	Black	208

TABLE XVI.

Of the absorption of different white materials exposed to the sun's heat.

Silk	108
White Cotton	100
Flannel	102
Linen	98

In Table XV. we see that the same material, if black, will absorb 208 per cent., or more than twice as much heat as it would when coloured white, and that every colour has its separate rate of absorption.

In Table XVI. the extreme difference due to *material in white* clothing is only 10 in 108 or 9·2 per cent.

In order to ascertain to what extent the sun's heat could be utilised to assist in the ventilation of a building, the author made the following experiment in May 1892 at Cawnpore:—

The air during the whole period of the experiment was slightly obscured by dust, the remains of dust storms and a very light N.-W. breeze was blowing. The observations were made at 2-0 P.M.

A tube of thin sheet iron 22″ square, and 10′ high, was placed on the roof of a room 27′ × 17′, with a height of 17′. The iron was left black and unpainted, and the opening into the room below was equal to the size of the tube. The best average of several experiments was obtained on the 17th of May, when the temperature of the air entering the tube, from the room, was 97°, and the temperature issuing was 113°, shewing a difference of 16 and a mean increase of 8 degrees.

The velocity of current through the tube measured by the passage of smoke through it was 10 ft. in 4½ seconds, or 133·2 ft. per minute, which, multiplied into the area of the tube (3·36 square feet), gives 447 cubic feet per minute, or 26,853 cubic feet per hour.

The air in the experiment was drawn into the room through a hole in the roof about 20 ft. above the level of the ground, giving a purer and cooler supply than if taken off the surface of the ground through the doorways.

The greater cooling power of the air on the roof, as compared with that of the ground level, was tested at the same time during the night with two similar porous water bottles. There was no wind, and the bottles were placed, at sunset, one on the parapet of the roof, and one on the ground. At 5-30 A.M. the temperature of the water in the bottles was found to be 72° in the bottle on the ground and 68° in that on the roof, the difference being 4 degrees in favour of the upper position.

Having reviewed some of the principal phenomena connected with the ventilation of inhabited dwellings, we may now turn our attention to the practical application of the physical data already examined.

Modern dwellings in India are built for the greater part without any regard whatever for ventilation. Of ancient dwellings, it is only the very large ones that remain to us, and their large interior spaces give us no idea of the arrangements of an ordinary house. There is every reason to believe that, as under most unconstitutional governments, there was no middle class, and that dwellings consisted only of palaces, forts, temples, and hovels.

Indian houses are chiefly remarkable for the area they cover without vertical openings. Detached houses are usually of one storey, and when the roofs are tiled, they are continued until within about eight feet of the floor, with rarely a practicable opening in their whole surface.

A roof 71 feet square, covering about 5,000 square feet of space without an opening, is by no means uncommon. The eaves descend to within 8 feet from the floor, enclosing a verandah which is generally protected from the sun by blinds of cane or reed; the walls are thus protected from the direct rays of the sun. These outer walls, with a total area of about 3,000 feet, are carefully whitewashed, and the tiled roof, having an area of 5,700 feet, all exposed to the sun, changes from bright red, when new, to dark brown, approaching black in the course of a few years.

This roof absorbs heat from the sun during the day at a rate due to its colour. At night it radiates both outwardly and inwardly, the inward radiation continuing long after sunset, until the temperature of the roof falls to that of the air within, and although the doors may be opened, the roof, like an immense umbrella, without any opening in it, retains a mass of hot air above the level of the doors, which greatly retards the cooling of the house. Even in the early morning the house is many degrees warmer than the outer air, and the effect of the roof just described is to raise, very considerably, the mean temperature indoors.

A terrace roof, as generally constructed, offers very little advantage over the tiled roof. It is white at first, when new, but it soon becomes black with fungoid growths, and, being nearer the floor than the tiled roof, is often hotter. Being of greater mass, it cools more slowly at night. The temperature has been observed as high as 120° on the parapet of a terrace roof which had been blackened by age and fungoid growth. This roof was used for sleeping on in hot weather, and, unless well watered at sunset, the temperature of the surface at 11 P.M. was uncomfortably high. One coat of whitewash kept this roof cool throughout the day, causing a considerable reduction of temperature within the house. Whitewash will only adhere to a clean surface: if applied to a surface blackened by fungoid matter, the lime will scale off.

An excellent lime-wash that will adhere to stone, iron, or glass may be made by mixing 10 per cent. of any common vegetable oil with the lime while slaking. The lime to be weighed dry. If the oil does not saponify, and incorporate with the lime, it must be boiled a little until the oil disappears. Castor oil must not be used.

The oil forms with the lime an insoluble soap, which, when once dry, will not wash off with heavy rain. It must be strained and applied in the usual manner. This coating was applied by the author to the iron roof of a large stable of the Bombay Tramway Company. The temperature of this roof at 2-0 P.M. in the month of October 1889, taken on the under side of the corrugated sheets, was 124° Fah. The temperature on the under side of one sheet on the same slope of the roof that had received one coat of the above mixture was 98° Fah.

A reduction of 26 degrees was thus obtained by means of a coating which cost 11 annas per thousand square feet, labour and materials included.

The temperature of the under side of a lean-to tiled roof, with the same aspect, and adjoining the stable, was 115° Fah., or 17 degrees hotter than the whitened iron. The tiles were old and discoloured. It was observed tha when the iron roof got a coating of brown dust, there was a slight increase of temperature, but the building, once the hottest of the Company's Stables, became the coolest during hot weather.

White is, without doubt, the best colour for the exterior of all buildings in India, both of roof and of walls. If other colours must be used for decorative purposes, they should be used sparingly. Even venetian shutters, or *jhilmils*, when exposed to the sun, should be painted white on the outer side, otherwise they become so many hot filters warming the air as it passes through them to the house. When the exterior has been properly attended to, the interior temperature and the ventilation are much more manageable.

Owing to the small difference which often exists between the air inside and outside of a house, openings for ventilation should be as much as possible at the highest part of the building, and with vertical passages, so that as soon as the outer temperature falls below that of the house in the evening, the warm air from within may escape rapidly.

A house of the bungalow type, already described, should have one or more large dormer windows facing away from the direction of the monsoon rains, and furnished with shutters that will open and close tight. All the rooms should have openings in the ceiling of not less than four square feet of area, protected by wire netting, through which all hot air would drain and escape. With such openings for the ready escape of hot air, lamps would assist in the ventilation of the rooms. General Morin, in his " Etudes sur la Ventilation," says that one cubic foot of coal gas when burnt will produce heat enough to circulate 1,000 cubic feet of air in a shaft. A lamp of 32-candle power burning for four hours would (p. 180) produce light equal to 10 feet of gas burned in one hour, and each foot of gas would yield 696 Units of heat, or 6,960 Units in all. But kerosine in relation to coal gas, for a given amount of light, only develops heat at the rate of 29 to 47. Therefore, $6960 \times 29 \div 47 = 4294$ Units, the amount of heat developed in four hours by a 32-candle power kerosine lamp. And $4294 \div 696 \times 1000 = 6170$, or the quantity of air in cubic feet that the lamp would put in circulation. Lateral holes in the walls are not nearly so good for ventilation as openings passing vertically through the roof, owing, as has been already stated, to the small difference which may often exist between the temperature of the inner and the outer air.

A Billiard Room, for instance, which has, probably, for its size the greatest amount of illumination, should have one or more openings in the roof, which offer the only satisfactory means of ventilation. If a shaft can be carried up 10 or more feet above the room, it will be all the better.

It has been shewn (p. 194) that while the sun is shining, its heat may be used for producing a current of air in a blackened shaft of good-conducting material. This experiment may be extended, when desirable, by placing the shaft on the ground, near the house, with a good exposure to the sun, and connecting it with the building by a masonry channel below the surface of the ground, terminating in one or more gratings in the floor.

Supposing the shaft to have an area of 3·36 square feet, as before, and a height of 60 feet. The air inlet will be in the roof 20 feet above the surface, and the temperatures in house and shaft similar to those of the experiment.

In the shaft we have a column of air with a mean temperature of 105° and weighing ·07031 lbs. per cubic foot, and that of the house at 97° will weigh ·07145 lbs. per cubic foot. We have then a column of air 60 feet high, which will balance a column of outer air equal in height to $60 \times {\cdot}07031 \div {\cdot}07145 = 59{\cdot}04$ feet. The difference between the two columns is 1·91 feet, and the theoretical velocity $\sqrt{1{\cdot}19} \times 8$, or 7·84 feet per second.

Allowing ·6 as the coefficient of efficiency, we have 7·84 ×·6=4·704 feet per second, which multiplied into the area of the shaft (3·36 square feet) gives 15·80 cubic feet per second, or 56,880 cubic feet per hour of air circulated. This air would be drawn through the house from openings in the roof, where the atmosphere is cooler, purer, and drier, than if taken from the surface of the ground; and after passing through the house will escape to the shaft by an underground passage.

This current, depending on the sun's heat, will vary with its intensity, and will cease at sunset. The shaft may, however, with the aid of a rotary fan, similar to that in the Thermantidote, be used to ventilate the house during the night with air taken at 60 feet above the ground.

A suitable fan for the purpose would be 3 feet in diameter, and would require less than half a man power to work it. In point of economy it would be cheaper than punkahs, as it would serve several rooms, and if beds were placed near or over the air grating, the sleepers would have all the advantage of being raised to a heigh, of 60 feet above the ground in a steady current of airt which, being constantly renewed, and much purer than the ordinary air of any house, should be much more wholesome.

Such a system of ventilation leaves the general arrangement of a house very much as it was before, but it furnishes a complete control over the air supply, and protects the inhabitants from the effect of malaria at night.

The ventilation of houses in large towns offers difficulties that do not appear in detached buildings. The municipal control of the construction of houses is a thing of very recent date, and it does not appear to take ventilation seriously in hand. Streets, the great lungs of a city, are only found where Imperial or Local Government has interfered in building matters. Crooked lanes and passages are the ordinary means of communication in an Indian town, and the absence of any systematic plan of communication renders the introduction of water supply and sewers a very difficult and costly operation.

The effect of the wind in renewing the air is almost entirely counteracted by the absence of straight streets; and when, the popular method of building is taken into account we have already a good half of the reason for the high rates of mortality.

Different communities seem to have peculiarities of ideas regarding the arrangement of their houses. In Bombay the Portuguese quarters of Orthobashi, Kalbadevi, Mazagon, and Matharpakady, there are many good houses with approaches so narrow and crooked that no wheeled vehicle can reach them. The old Mohammedan quarters have comparatively good streets, while the wealthy modern Khojas build expensive houses in crooked, narrow, and unwholesome streets. Hindus seem to prefer wider streets, but until the Government interfered, directly, or indirectly, all the streets were crooked —unless the houses abutted on a main road.

Systematic ventilation, as understood in Europe, is so far beyond the ideas of the average Native of India, that any attempt to introduce it would lead to resentment and failure. The ventilation of wide and straight streets, an outcome of Local Government, has been accepted more on account of the improved means of circulation it provides than for any hygienic merit the innovation might possess.

The ventilation of dwellings can only be enforced on its broadest lines, as, for instance, by regulations regarding the area of a house and that of the surrounding unoccupied ground, the depth of the building between exterior walls, the amount of window area, and the erection and lighting of stairways. Bombay, on account, doubtless, of its limited area and its industrial activity, furnishes examples of density of population unequalled, probably in the world. An exception might perhaps be made in favour of some Chinese towns.

The density of urban population *per house* in Bombay in 1881 was 25, while in Calcutta it was 11·6 in the same year. The extreme density of population per acre is in—

London	222
Calcutta	208
Bombay	760

In houses per acre Bombay has a maximum of 35, while London has about 22.

Generally speaking, the greatest density of population in London is less than that of any out of twelve Sections of Bombay, which average 458·57 persons per acre.

The foregoing figures, taken from the census returns of Bombay for 1881, prepared by Surgeon-Lieutenant-Colonel T. S. Weir, Health Officer, are eloquent of conditions of life which were not contemplated in any Sanitary work written upon European experience alone.

In the climate of Bombay, which has no cold season, the poorer classes live in the open air for a great part of the year. Their houses are used to protect their personal property, but they sleeep by preference in the open air. During the monsoon rains, when all must seek shelter, overcrowding takes place to a very great extent. The only limit to overcrowding seems to be the number that can possibly lie on the floor or on the scanty furniture.

Eight persons have been known to sleep in a room ten feet by ten, and eight feet high, with door and window closed, until the atmosphere could only be accurately described as sewer gas. Each person, in the case above quoted, would have only one-sixth of the air space allowed by de Chaumont for the English climate and in a *properly ventilated* chamber. Dr. Angus Smith, in treating of the effect of continuing to breathe a very limited atmosphere, says that a man shut up in a tight room $8' \times 9' \times 8'$, containing 576 cubic feet of air, could not breathe in it for 24 hours without uneasiness. At the end the atmosphere would have the composition of expired air: a morbid state, and death would ensue. Six hours in one-fourth of the space or 144 cubic feet would bring about the same result in a tight chamber. In the Chawl or lodging room each of the eight men had only 100 cubic feet of space, and reckoning his night at eight hours, he would have been in worse case than that instanced by Dr. A. Smith, were it not for the very easy fit of door and window shutter. Glass is, of course, unknown in such dwellings.

Outlets for the smoke of cooking is about all that can be insisted on in such buildings. Some good examples of roof ventilators may be seen on some new Chawls built by the Health Department for the conservancy men in Bombay.

In the interior of India, where the range of temperature is much greater than on the sea coast, the habits of the people at night will account to some extent for the high death-rate prevailing among the poorer classes. In Cawnpore, and in Lucknow, a large proportion of the houses are of only one storey, so that although the population per acre may be much less than that of Bombay, the house accommodation is far below the requirements of the people. During the nights of the hot season the people sleep in the street, and to avoid the cart traffic of the night or early morning, their charpoys or beadsteads are straddled across the open sewer that passes every door. This position, which is doubtless the least of two evils, indicates the very unwholesome conditions that must exist indoors.

In the winter season, when the nights are too cold, and damp with fogs, to permit sleeping out of doors, the people crowd within, and close all openings as much as they can. After passing the night in a very impure atmosphere, they go out half clad into the raw cold air of the morning. It is no wonder that the mortality during the cold weather is greater than at any other period of the year, although the cold is only felt between sunset and sunrise. Conservancy and good water supply may modify, but they cannot remove the diseases that arise from such a cause.

In houses of a better class the absence of interior corridors and independent approaches to chambers is one of the commonest defects interfering with a through current of air. The stairways have no provision for lighting, and in many large houses they require artificial lighting by day as well as by night, and having no opening at the top they contribute little or nothing to the ventilation of the building. A house may have a frontage of 25 to 30 feet, a depth of 80 to 100, and a height of four or more stories. It may be flanked by a 3-foot gully on each side into which the greater part of the windows open and from which they receive light and air. The gully is a shoot into which every kind of refuse, solid and liquid, is thrown from kitchens and living and sleeping rooms.

To ventilate such houses adequately would be impossible without the aid of steam power. To demolish and rebuild them is beyond the means of any Indian municipality.

Good conservancy and water supply, with compulsory ventilation of interior stairways, is about all that a municipality can provide for such a type of building.

In the meantime, cheap transit by means of railways and tramways is doing much to relieve the density of population, especially at night, in the largest cities in India, by bringing suburban localities within easy reach. The average rate of 3rd class fare in India by railway is 2½ pies per mile or one farthing, while the average rate on English lines is three farthings.

Improvements in the construction of dwellings in India must be initiated and carried out by Europeans for their own personal benefit, and to suit their own domestic arrangements.

At the present time the houses occupied by Europeans in India are, with few exceptions built and designed by Natives who never saw a house in Europe and who will not employ European architects. Any Native of India, when he has sufficient money to pay for building, considers himself competent to design and superintend the construction of a house of any size with such assistance as the builder may give him. The builder very naturally encourages this habit, as it gives him more freedom with less responsibility. The result is a building which, although it may be intended for the exclusive use of Europeans in a cantonment, has all the general arrangements of a home for Natives, whose domestic arrangements and habits are totally different from those of Europeans. This causes a considerable waste of space combined with exceedingly defective ventilation.

Much of the constitutional wear and tear of Europeans in India is due to improper housing, and very few of them appear to be conscious of the precautions in living that are rendered necessary by the change of climate they have accepted in leaving Europe for India. It cannot be too often repeated that the difference of *mean temperature* between, say, Calcutta and Edinburgh is 30·4 degrees; that this difference is equal to 30·8 per cent. of the temperature of the blood above zero, and that in spite of this increased mean temperature in which they live, the blood cannot vary by more than three-quarters of one degree without affecting the health. There is a constant tendency for the blood to become too hot in India, and any failure in the arrangements for the escape of surplus annual heat results in fever. The European, whose constitution has for centuries been trained and adapted to the conditions of a temperate climate, should never forget the abnormal circumstances under which he lives in the tropics. When the temperature of the air rises above that of his blood (98·4), a slight derangement due to chill may raise his temperature several degrees. Apart from the risks of actual illness, he may live in a condition of perpetual discomfort from causes, which a reasonable attention to the principle of hygiene would enable him to avoid. Of these, a constant renewal of the air supply is among the most important.

An efficient system of ventilation, giving an ample supply of pure air in dwellings at all times, and quite independent of the winds or seasons, is only practicable in large buildings containing many houses or sets of rooms, whose tenants are able to pay for the necessary apparatus and motive power to ventilate by fans. Various circumstances combine to render it probable that, for Europeans in the largest Indian cities, well-built tenement houses will take the place of the isolated bungalow with its expanse of waste space, its luxuries, and discomforts. The increasing number of those who live in hotels in Bombay and in Calcutta is a clear indication of the dearth of convenient small houses, while the class of Natives who put their capital in house property have found that building *chawls* or tenement blocks of from one to four stories for the labouring classes is a much better investment than building Native bungalows for European occupants. Each chamber of a *chawl* is 10′ × 10′ × 8′, and will let for as much as Rs. 3 per month, the annual outlay for paint, glass, and colour-washing is *nil*, and the limit of numbers that actually inhabit one room is left to the taste of the tenants themselves. The rent is thus reduced at times to six annas per head per month by a combination of eight tenants.

Apart from the large hotels and the residential clubs, a few attempts have been made in India to provide convenient chambers for the better class of Europeans.

All of them have fallen short in essential points of what is wanted. Some made no accommodation for servants on duty, some had no main staircase, most of them had defective ventilation, and all had more or less imperfect sanitary fittings. Despite the increasing intercourse and happy growth of friendly relations between

Europeans and their Indian fellow-subjects, their domestic habits are, and will remain, so widely distinct that each requires a house built on totally different lines. Their ways are so different that many of them, both Native and European, consider that they should occupy separate parts of the same town, not from any sense of antagonism, but for greater convenience.

In a town, such as Bombay, for example, a good tenement house should not be less than six stories in height, built around an interior court that should not be less than one-fourth of the area, in plan, of the building. The floors need not be more than 13 feet apart. The top floor would then be 69 feet above the street, including a plinth of 4 feet. For those who are able to mount 69 feet to their dwellings, the advantage of living, and, above all, of sleeping, at such a height are most important. The greater coolness, dryness, and purity of the atmosphere, the absence of flies, and of the too familiar smell of drains, all combine to render a fifth floor a most desirable place of residence.

The balconies should have at least one-third of the floor area, and the building should face four streets, so as to be safe from interference of other buildings.

The interior court should be connected with the streets by means of at least two arched passages, of sufficient area to allow of free circulation of the air. The stairs should be all of stone, with main stairs not less than 5 feet wide and properly lighted; all floors of concrete or hollow brick, both for safety against fire and to deaden the sound of footsteps above. There should be no stables in the building. Ventilator openings should be provided just below the ceilings and independent of doors and windows, and the kitchens, if the odour of cooking must be kept from living rooms, would have to be on the flat roof along with a laundry, for the necessity of which, on the premises there are very sound hygienic reasons. Quarters for servants on duty, as well as sleeping accommodation, would have to be provided. The details of sanitary fittings would be of two classes : those of bath-room and water-closet of the English pattern, discharging through syphons into down-take pipes, properly ventilated by a parallel pipe connected at each story and terminating above the roof.

The drainage from the kitchens and the servants' quarters would need to be fitted as described (p. 83), but discharging into covered catch-pits, which would overflow to the sewer. Every care should be given in the design of the house to provide such facilities of communication, &c., as will reduce the number of servants, for in a small house, such as we are dealing with, each additional "boy" is a serious complication.

Nothing short of the most vigilant European management will make a permanent success of such an establishment as has just been described. Regulations may be drawn up with the utmost care in the common interests of the tenants, and subscribed by them in the best of faith, while their servants will display the most perverse and startling ingenuity in infringing them. Shaking mats in stairways, cleaning boots on landings, cooking on landings, shaking carpets at wrong hours, and throwing sweepings and water from balconies and windows, must be strictly suppressed, else the property will deteriorate in value and the class of tenants will change.

It is but a step from the arrangements of the above building to one in which the air supply does not depend on exterior currents or on the temperature of the body, but is provided by a ventilating fan, which draws air from a short shaft on the roof of the house at say 90 feet from the ground and delivers it in a constant current day and night into every inhabited room. Structurally the building would be very little altered. It would probably be two rooms thick, with an interior or exterior corridor to make communication between the rooms on each floor. In the roof of this corridor the air conduit would be formed by a false ceiling enclosing a space of the cross-section required for the passage of the air. A tube 6 feet wide and 1¼ feet deep would pass air for 54 persons at the rate of 5,000 cubic feet each per hour and air for 200 persons could be circulated with an expenditure of about ½ horse power.

A 1 horse power kerosine engine, such as is at present in use in Bombay, can be run for 24 hours at a cost of 22 annas for fuel.

The total cost for one month's running of such an engine, including wages, repairs, up-keep and depreciation of fan &c., would be Rs. 109-8-0 or Rs. 0·547 per head per month divided among 200 people.

If a double set of apparatus were used so as to have an unfailing supply night and day throughout the year, the cost per head per month would rise to Rs. 0·621 per head per month.

The introduction of a constant supply of pure air amounts practically to a change of climate, and the purity of the air taken at from 90 to 100 feet above the ground in Bombay would in all probability be greater than the air at any of the hill-stations that are so much resorted to by its inhabitants.

The ground floor would share the same atmosphere with the 6th storey, and kitchens might be established on any floor as the ventilation of all the rooms would be *from within outwards.* It is likely, however, that the construction of such a building would soon be followed by the establishment of a good restaurant in the ground floor from which food supplies might be obtained by those who wished to avoid the care of a kitchen.

Thorough ventilation has great advantages for men whose days are spent in active work and whose nights should restore their lost energy by the most complete repose, whatever the weather or the season may happen to be; but for women and children who pass the greater part of the day and night within doors, it should prove invaluable. So much of the lassitude of the "long, long Indian day" is due to bad ventilation, and so much of the feverish restlessness at night, that does duty for sleep, may be traced to the same cause, that the health of families, living in a pure and constantly renewed atmosphere, should show a prompt and permanent improvement. Holidays to a family so circumstanced would be really holidays and not a period of convalescence, as they so frequently are in fact; and the effects of the climate, even upon those who could only pass their nights in the atmosphere of the fan, would, doubtless, be greatly modified.

A fan is one of the few machines that may be worked by an engine driving electric light machinery, so the two might be combined if desired under the charge of the same man. The heat produced by incandescent electric light is so small that the heat of lamps or of gas light might be reduced to a fraction. Smaller rooms may be used, when the circulation of the air is assured, than would be comfortable without the aid of a fan, and the difference of the size of the house or chambers would probably balance, in rent, the extra cost of ventilation leaving the improved hygienic conditions as pure gain.

Among the necessities and luxuries of modern life a pure and constant supply of air may rank *at least* next to that of good water, and before either gas, electricity or telephones; and its cost of application when compared with what the breathing of vitiated air costs in health on money leaves no doubt as to its practical economy.

CHAPTER IX.

VENTILATION OF HOSPITALS.

If pure air has more importance in any one place than in another it is surely in a hospital, where every science is put under requisition to combat disease. The importance of pure air must, if possible, be greater in a warm than in a cold country, on account of the more rapid decomposition of dead organic matter, which is liable to accumulate in the vicinity of human communities.

It is unfortunate that in spite of the large sums that have been spent in India on the construction, furnishing and maintenance of hospitals, the subject of ventilation has been almost entirely neglected. If ample cubic space per patient, and plentiful communication with the outer air were sufficient, there is little to complain of, but if air for breathing may be regarded as a medicament which should be supplied of the best possible quality, to the patient, there is scarcely a hospital in the country that is not open to the charge of administering an inferior article.

Hospitals are not only institutions for the cure of disease, but centres of infection as well, and it is only by means of special precautions that the congregation of the sick does not multiply disease.

The importance that is now attached to antiseptic treatment proves how thoroughly alive surgeons are to the necessity of extreme cleanliness, and yet the position of a hospital, especially in a large town, is frequently so bad from a sanitary point of view that the rate of recovery from operations or disease is considerably retarded.

It may frequently happen that a patient finds, in the hospital, an atmosphere inferior in point of purity to that of the private house he has just left.

The position of a large hospital in a city is not a mere matter of choice; the convenience of patients, and other considerations, often determine its location amidst insanitary surroundings, and the building is usually of only one storey.

The Jamsetjee Jejeebhoy Hospital of Bombay may be taken as a type, and by no means the worst one, of a large hospital in a large city. It is throughout a one storey building or series of buildings, suitably isolated and well drained. It contains about 300 beds, and has attached a Medical College which trains about 150 students, male and female.

The hospital is not crowded by surrounding buildings, and has a good margin of land about it. It stands, however, in the midst of a densely built and densely populated part of Bombay.

Between it and the sea in the direction of the prevailing west wind lies 1¾ miles of land, part of which is marshy and part densely populated by the poorer classes; and the wind, blowing over this district from the Arabian Sea, loses a good deal of its original purity. The action of the wind blowing over a town is not that of one solid plane object sliding over another. That part of the wind in contact with the houses or the ground eddies and rolls on its passage, taking up many impurities on its way. The vertical circulation that is set up by the sun's heat absorbed by the surface of the ground and by buildings, carries up foul air from alleys and gutters, and the more slowly the wind travels over such a district, the more of these impurities it will take up. Passing over houses and coming to an open space, the current of air descends until it meets with new obstructions.

In this manner the hospital, with all its wards raised slightly above the ground level, is ventilated with air of considerably reduced purity assuming the sea breeze to be the standard.

The quantity of air passing through the wards depends almost entirely upon the velocity of the wind, and when we follow up the question of air supply to single individuals, all idea of systematic ventilation is lost.

Ventilation here means the passage of a certain quantity of air in contact with, and past a patient, to remove the impurities of respiration, the vapour from lungs and skin, the emanations from the body and lungs, and the surplus heat of the body. These are all being given off constantly, and can only be removed by the air. If, therefore, any interruption occurs in the rate of current, it will cause an accumulation of impurities about the patient, and those impurities, even if they were only those of a healthy person, would be injurious to the sick. The vigour of a healthy man varies directly with the purity of the air he breathes, and so sensitive is he to a change in this respect that his feeling of well-being is immediately excited by rising eighty or one hundred feet above the ground level in any town.

The absence of data regarding the impurities of the atmosphere, and indeed of air analysis of any kind in India, is a most regretable circumstance, as it prevents any calculation as to the exact minimum quantity of air that should pass each patient per hour in a hospital. Even in Bombay where immense sums have been expended in sanitary work the Corporation refused to sanction the expenditure of Rs. 300 a month for some months on air analysis which would have been of the greatest value in furnishing a true and reliable basis for many of the works on which the health of the people depend.

There is every reason to believe, from statistics of mortality, from the higher rate of decomposition, the low average velocity of the wind, and the long periods of dry weather, that the air in Indian towns contains more organic impurities than in English towns.

Referring to the experiments of Mr. Tichborne (page 16) on the dust in the streets of Dublin, where a difference of 52 per cent. was observed in the organic matter in the street, and at a height of 134 feet above it; that is to say, the air near the ground contained 52 per cent. more of organic dust than that found at 134 feet above it.

Referring also to the observation of Fedor of Buda-Pesth (page 17) on the greater proportions of carbon dioxide observable at the ground level than at one metre above it, and to the fact that the gases of decomposition are, at equal temperatures, nearly all heavier than atmosphere air, there is sufficient evidence to prove that patients living at a height of from four to five feet above the ground, and breathing such air as may chance to come in by the doors and windows, are not in the best hygienic condition for recovery. The diagram on plate I. has been prepared with a view to trace, if possible, any relation which might exist between certain meteorological phenomena affecting the state of the atmosphere, and the hourly death-rate, during day and night. The diagram is divided by vertical lines into twenty-four parts representing the hours from midnight to midnight. The curves traversing these lines represent the fluctuations of each of the phenomena under observation: they are reduced to *equal height* for the purpose of ready comparison, but the height represents no scale. The relative height, in every part of each curve, is however correct.

Curve B represents the mean daily variation of the barometer in Bombay during a period of six years, shewing that the maximum pressure occurs at 10 A.M. and at 10 P.M., and the minimum pressure at about 4 A.M. and 4 P.M.

In Bombay the actual daily variation of barometric pressure is, fortunately, very small, being only one-tenth of an inch. The extreme variation is 0·584 of an inch of mercury, or 7·963 inches of water, so that if decomposing sewage were confined in a sewer between two syphons, the gases would blow through, if the seal were not more than 7·963 inches in depth when the barometer was at its lowest height.

Barometric pressure, although it does not affect the total amount of gases that escape from decaying matter, determines the rate at which it escapes at various hours of the day. This is known to inspectors of nuisances, who have observed that at about four o'clock in the morning, and the afternoon, smells from drains and from nuisances are most offensive. The escape is retarded after these hours until about 10 A.M. and 10 P.M., when the barometric pressure reaches its highest limit.

Curve A represents the varying rate of mortality in each hour of the day. It is made up from the registers of death at the Jamsetjee Jeejibhoy Hospital at Bombay, covering a period of nearly four years. Only deaths from sickness have been counted, and all deaths from accident, violence or poison have been eliminated.

Curve E, of Vapour Tension, which is lowest at the mean hour of sunrise, corresponds with the Temperature curve D, at the same hour 6 A.M., because it is the temperature of the air that determines the quantity of water vapour it may hold in suspension. Just before sunrise is, therefore, the dampest period of the night, and the air at this time, loaded with water vapour, is in the condition best calculated to absorb the gases of decomposition that have been escaping freely between three and five o'clock. Curve C, of Atmospheric Electricity, is the one of which the least is known. It is frequently in close harmony with the barometric curve, but it is at the same time so erratic that no true theory has so far been deduced from its movements.

It is quite possible that the sensations some persons experience previous to a storm, and which are popularly attributed to electrical agency, are due to the increased impurity of the air caused by low barometric pressure and a stagnant atmosphere.

Taking curves B, D, and E together, we have evidences all pointing to an accumulation of the gases of decomposition along the surface of the ground in the early morning, and being heavier than the air, they would lie on the surface until the sun's heat by warming the ground would put the gases in movement and lead to their dilution in the upper strata of purer air. Although at 4 P. M. the barometric pressure is lower than in the early morning, and the discharge of gases of decomposition greater in consequence, the circulation due to the warmth of the earth's surface is much greater than that of the morning; and the state of the air, if analysed, would in all probability be found less noxious.

The curve A, of hourly mortality, has such a close correspondence with that of Barometric Pressure, that unless men are admitted to have an inherent tendency to die at certain hours, rather than at others, there is a very strong presumption that the impurity of the air at certain hours, and the rate of mortality, stand to each other in the relation of cause and effect. When life is hanging, as it were, by a thread, a very small circumstance will often suffice to determine the fate of a patient, and the wave of malaria that passes over him twice a day may have carried off many a valuable life which better surroundings might have saved to his friends and to society.

If the ventilation of hospitals is to be made equal in efficiency to their medical and surgical resources, it must no longer depend on hazard, but must be as strictly under control as any other service in the establishment. The wind is not to be depended on, and the difference of temperature between the body of a patient and that of the air about him is not sufficient to produce a current rapid enough to carry off the exhalations of his body unless assisted by independent currents.

Air is the most plentiful of all known substances, and the cost of any supply is only that of the mechanism requisite to obtain it, and as a building 100 feet high would be too expensive for the resources of any hospital, the principal advantages of such a building might be obtained by constructing a shaft in the form of a chimney or tower of 100 feet or any other desired height, in order to bring down a supply of pure air for distribution. The air would be carried in underground passages of watertight masonry from the shaft to the wards, or in wooden passages overhead when more convenient. The distribution of the air could be effected by means of a double ceiling in corridors or verandahs in old buildings, and by conduits below the floors of new buildings. By means of suitable openings above or below the beds, each patient could be enveloped in a constantly moving atmosphere with a fixed rate of current.

Three hundred patients, with an allowance of 5,000 cubic feet of air each per hour, would necessitate the use of a ventilating fan with a wheel 12 feet in diameter and 6 feet wide, running with a speed of 36 revolutions per minute and delivering 25,000 cubic feet of air per minute. The vertical shaft would be 6½ feet square, and a one-horse power engine would suffice to drive the fan.

There is now a liberal choice of sources of power for such a fan without using steam. If water power were used, there is sufficient pressure available to allow the water, after driving the fan, to be delivered into a tank of sufficient height to flow to the supply taps. Petroleum engines are already a success in Bombay, and work very economically with the kerosine of commerce.

Bullock power is always available, but is not so steady for constant work as the others.

A ward of 16 beds could be ventilated by a 3-foot fan driven by a couple of punkah coolies working in turns.

Doors and windows would have to be kept shut, at least on the weather side of the building during the day, and on all sides during the night, in order that the hospital might be filled with the pure air of the shaft. Ventilation by pressure is alone advantageous, as by suction air would be drawn in from the surface of the ground. This system of ventilation, assuring as it does a proper supply of air to each patient, necessitates a much smaller cubical space per bed than is now required; in fact, a smaller building.

The same precautions as are recommended regarding the exterior of dwelling houses (p. 197) should be carried out on hospitals. They should be whitewashed both on roof and walls, and kept white, while within the colour should be one that, admitting of a fair amount of illumination, would not fatigue the eyes of sick persons.

If the use of oxygen as a stimulant should gain in popularity in Indian medical practice, the system of ventilation advocated in this chapter would greatly facilitate its application. Introduced from a cylinder, and through a meter, into the air passage of any single bed, the proportion of admixture could be regulated and maintained for any length of time without the necessity of filling the room with the mixture. Low screens around the bed could be used to envelope the patient more completely in this oxygenated air bath, which would amount practically to an immediate and continuous change of climate.

It is worthy of note that the difference of mean temperature amounting to 30° referred to (p. 18) existing between Edinburgh and Bombay, while reducing the specific gravity by 4·308 per cent., reduces the quantity of oxygen it contains in similar proportion.

If a lower temperature is sought in the hills by a sick person living near the sea level, he finds that the expansion of the air which at sea level was due to heat is still to be encountered on the hills owing to reduced barometric pressure. The reduction of oxygen per cubic foot of air due to this cause may be compensated by the use of compressed oxygen as described above.

Public buildings in India, such as churches, theatres, and places of assembly, where people meet in crowds for several hours at a time, have no special provision for ventilation. The door and window openings, and, rarely, openings in the roof, are all that are provided. These openings are generally there more as architectural features than as ventilators, and are of very little use to people in a crowded room. In the pit of theatres, where spectators have frequently only five square feet of floor space, twenty will sit on one hundred square feet of floor, and each individual should be provided for at the rate of 5,000 cubic feet per hour. This is much more than their personal requirements, but, as will be seen, it is the simplest method of ventilating the house. There is only one possible method of distributing the air in a closely-packed audience, and that is by ventilating through the floor. The floor of a theatre lends itself readily to this kind of ventilation, being built in steps. By means of openings in the face of the steps, each individual could be supplied directly with a steady flow of fresh air, which, if the openings were 2 feet wide (the width of a chair) by 4 inches high, would enter with a velocity of 1·8 feet per second, and would rise around the individual at an approximate rate of 52 feet per minute. The air should escape at the back of the galleries, and would then traverse the whole of the house without the necessity of carrying the air passages to the upper parts of the building. The space below the floor would be paved or plastered, and being completely enclosed would form a distributing air chamber into which a ventilating fan would discharge. The fan would draw its air supply from the roof.

A fan to supply 200 people with air at the rate of 5,000 cubic feet each per hour could be driven by a bullock, a small water motor, or a petroleum engine using common kerosine. Theatres in India are all private property. They are small and so badly ventilated that the discomfort of passing an evening in them detracts much from the pleasure the performance should afford. There can be little doubt that they would be much more frequented if the air supply received adequate attention.

In churches and halls for public meeting, where the floor has no space below it, channels would have to be made below the floor, lined with watertight masonry and plastered. Communication would be made with the room by means of light metallic gratings with holes small enough to carry the leg of a chair. If columns existed in the chamber, air might be made to escape around the base from a false plinth in addition to the openings in the floor. Whatever is done in the way of ventilation for the comfort of an audience must be done *among them*, and must take effect equally over the occupied area and within a height of about fifty inches in which the audience sits. If sufficient air were carried in at one side of such a building and out of the roof, it would miss more than half of the assembly. If it blew in at one side, and issued at the other side, over the head of the people, the distribution would be very irregular, draughty in one place and close in another. This may be observed in the Town Hall of Bombay at any public meeting. The hall is large, with many glazed doors of ample dimensions. In the winter season, during a concert, people may be seen shivering near an open door, while others are uncomfortably warm in the middle of the room.

Floors, having an empty space of several feet below them, may be laid with space between the boarding. Four-inch flooring boards, laid with $\frac{3}{8}''$ spaces, would, for every five square foot of surface, have ·367 square feet of opening, and if 5,000 cubic feet of air were passed through, the velocity per second of the current would be 3·7 ft. With ½″ spaces the velocity would be reduced to 2·9 ft. per second, and if 3″ boards with ½″ spaces were employed, the velocity of the 5,000 cubic feet per hour passing through would be 2·1 ft.

The floor of the Crystal Palace at Sydenham is laid in this manner.

The spacing of the flooring boards will be decided by the purposes for which the room is intended to be used.

Among Courts of Justice in India, some of the worst examples of bad ventilation may be found. Owing to the noise that an Indian crowd *will* make in the corridors and outside of a court, the doors have frequently to be shut, in order that the business of the court may be heard. Crowds in any court usually contain a large unwashed element, and a court house soon acquires a kind of menagerie smell, familiar to all who frequent them, which seems to impregnate the walls, and remain even when the building is empty. Dr. Angus Smith, in his researches into the composition of the air in public buildings, found that in the Court of Queen's Bench, London, on the 2nd February 1866, the proportion of oxygen of the air was only 20·65 per cent. out of a possible 20·95, the proportion in open places in London. This is much worse than the pit of a theatre at 11-30 P.M., or the gallery at 10-30 P.M.

The air of the Queen's Bench stands next in order to that of metalliferous mines, and the state of many Indian court houses would probably be found very little better.

The administration of Justice for many hours together, day after day, in a very foul atmosphere is not only very bad for the highly educated and highly paid men who preside in the courts, but bad also for the work they do. It is impossible to work long in a badly ventilated court without suffering an amount of bodily and mental fatigue, which must militate against good work, and which is all the more to be deplored as it is quite unnecessary. Poisoning, by means of twice or thrice breathed air, is a slow process, involving slow deterioration which may continue for years, with intervals of change and recuperation, but the average intellectual vigour of any man in such circumstances must be a good deal under par.

The following eminently practical rules, for the ventilating and lighting of School Rooms, have been drawn up by Mr. T. B. Kirkham, Educational Inspector, Central Division, Bombay, and issued by the Educational Department :—

Lighting.

" 1. Good lighting of school or class-rooms depends upon (1) sufficiency of light, (2) distribution and employment of the light to the best advantage.

" 2. As regards sufficiency, the general rule is that the apertures for light should be about equal to $\frac{1}{5}$th of the floor-area of the room to be lighted. A room 20 feet by 20 feet requires about 80 square feet of light. Another calculation is that there should be 200 square inches of light for each pupil, but something depends upon the situation and aspect of the building, and it is generally easy to see whether a room is sufficiently lighted or not.

" 3. As regards using the light, the thing to be kept in view is the avoidance of all strain or tension on the eyes of the children. Strain is caused either by an excess or by a deficiency of light. Working in shadow and working in glare are equally injurious. The seats should be so arranged that the largest possible number of children may work in light *falling from the left side and as far as possible from above.* Side light from the right is the next best, whilst light from behind is bad, because the body throws a shadow on the work. The worst light of all is that from the front falling on the faces of the children. This is most injurious, and should always be avoided. Where desks are used, the window sills should be higher than the desks, as light from below is confusing and fatiguing. And the windows should be fitted with shutters to exclude the direct rays of the sun, when necessary. It may be added that in night schools the artificial light employed should be steady, and not flickering. Colour-washed walls are preferable to whitewashed, which are apt to cause glare. French grey, light stone colour, or the light blue so easily procurable in these parts, distributes the light in the room much better than white.

Ventilation.

"4. Good ventilation, in like manner, resolves itself into (1) sufficiency of air or cubic space for the number of children to be accommodated, and (2) arrangement for changing the air as fast as it is used up.

"5. As regards sufficiency, sanitary authorities claim a space of 200 cubic feet or upwards for each pupil, but in India, where doors and windows are habitually kept open, a measurement of the floor-space is sufficient for all practical purposes. Assuming that the rooms are at least 10 or 12 feet high (14 feet is a better height), a minimum floor-space of 10 square feet should be allowed for each child in attendance in a primary school, whilst 15 square feet and upwards should be allowed in secondary schools. For youths and big boys, 20 to 25 square feet per pupil is not too much.

"6. With regard to the changing of the vitiated air, the thing to secure is *circulation without draughts.* The prevailing winds should be admitted, and the impure air should be allowed to escape, whilst at the same time the breeze should not be allowed to play directly upon the bodies of the children.

"7. From the above it will be apparent that the best windows for school and class-rooms, both for Light and Ventilation, are those which have deep window sills, say 4½ feet high, and which go up high towards the ceiling. With such windows the light falls from above, and the children are at the same time protected from draughts. Small lattice window panes are objectionable. In ordinary cases, iron bars and wooden shutters on hinges answer best. Windows not protected by verandahs should have 'hoods,' so that they need not be closed for sun or rain. Perforated zinc has in many cases been found to prevent sufficient change of air, and should only be adopted after careful trial. It need hardly be said that every class-room should have all its doors and windows thrown open, and be *thoroughly flushed with fresh air during every recess* and on every other available opportunity. In all new buildings, and wherever it can be introduced in old ones, 'Ridge ventilation' should be adopted.

"8. The following simple test for impure air may occasionally be useful: Take a bottle of 10½ fluid ozs. of pure water. Blow the air of the room into it by means of a small bellows, or, in the absence of bellows, agitate the water so as to make it absorb the air. Pour ½ oz. (a tablespoonful) of lime water into the bottle and cork and shake. If milkiness is produced (by the combination of the lime and carbonic acid producing chalk), it shows that carbonic acid gas was present in the air in poisonous proportion. The sense of smell, however, is usually a sufficient test, unless it has been blunted by staying in the vitiated air. If the arrangements are proper, *there ought to be no perceptible difference on entering from the fresh air.*

T. B. KIRKHAM,
Educational Inspector, C.D.

Poona, 1*st January* 1889."

CHAPTER X.

VENTILATION OF MILLS AND FACTORIES.

There are certain reforms which, even in the most civilized communities, are never carried out, except under the pressure of legislative interference. They may after a time come to be regarded as reasonable and necessary, but their introduction is generally met either by active or at least by passive resistance. The Alkali Act, which prohibited chemical manufacturers from poisoning the air and the rivers in their neighbourhood, was regarded by many as the harbinger of ruin, although it very soon proved to be the source of renewed prosperity in providing the stimulus that resulted in new processes for the utilization of waste products.

In the English cotton industry, successive Acts of Parliament have been passed regulating the hours of labour and the age of labourers, and more recently the reckless use of steam in weaving sheds has been restricted by law. Under the pressure of the latest Act, mill-owners have discovered that weaving may be satisfactorily performed without the sacrifice of health and of life among the operatives that had previously taken place in consequence of "steaming." The moisture from steam discharged into the weaving shed facilitated the process of weaving, but in cold weather, when the operatives left their work with clothes saturated with moisture, they were chilled and suffered much from inflammation of the lungs, pleurisy, and consumption.

Systematic ventilation has no place in the design of an Indian Mill. Neither owners nor managers have (with rare exceptions) studied it. The building is a copy, with little or no variation, of some other mill, and if any extra expense is indulged in, it is for machines, and not for buildings.

As a basis for comparison, of buildings in India and in England, the following details of a spinning room of 15,000 spindles will assist our inquiry into the air supply of the operatives:—

TABLE XVII.

	England.	India.
Length of room in feet	147	220
Breadth „ „	132	90
Height „ „	15	15
Cubic content in feet	291,060	297,000
Working staff of men and boys	40	80
Cubic feet of space per head...	7,276	3,712
Floor space per person in square feet ...	485	247·5
Length of working day in hour	9	12
Value of operative per cent.	100	50
Value of operative in equal time	100	37·5

In the foregoing table the principal features are that twice the number of people work in almost the same space in India as in England, and that their day is 33 per cent. longer. Yet the Indian operative only performs 37·5 per cent. of the work of the English operative in a given time. The nature of the work is not laborious; it does not demand the exertion of the smith, the washerman or the dock labourer. It is nevertheless exhausting, for it necessitates a constant alertness of mind and body—of eye and hand, admitting of no neglect that does not involve a corresponding loss in production. Each spindle is capable of producing so many ounces of yarn a day, provided it is kept fully occupied and fed; and every minute of stoppage represent so much loss of yarn.

It is scarcely necessary to add that when the number of spindles reaches fifty, or even one hundred thousand, the loss by neglect may amount to a great deal in a single day.

Every window in the mill has a part that will open, but the idea that every human being in the building should be supplied with a certain and sufficient supply of pure air, at a uniform rate, at all seasons, and in all weathers, never entered the head of any mill-owner in India. Yet the difference of energy between his operatives and the workers out of doors lies mainly in the impure air of his mill. The window openings are generally placed at such a height that they can only remain open in a very light breeze. If the breeze increases, the windows on the weather side are closed, because the current would interfere with the yarn in process of manufacture, causing it to break. The supply of fresh air is thus cut off from one side of the mill. If the air becomes too dry for the purposes of manufacture, all the windows are closed, and the operatives work from morning till night in an atmosphere of which the foulness is constantly increasing.

As a dry atmosphere renders the cotton fibre hard, refractory, and difficult to spin, the floors are sluiced with water so as to moisten the air. At first this has a cooling effect, but as the air of the room is not changed, the vapour is gradually heated to the original temperature of the room and becomes almost intolerable. To this we added the stenches from the dirt on the floor (decomposed by the water) and the emanations from the lungs and skins of the operatives, the whole forming a compound which is poisonous and which should be the subject of severe legislative measures. It is a curious and significant fact, that in the reports of all the labours of Commissions on the Factory Question, there has not been published a *single analysis of the air that the work-people have to breathe.*

It is difficult to avoid one of two conclusions, either that the members did not know that a report would be incomplete without air analysis, or that they purposely avoided the subject. Wholesome air, according to Angus Smith, contains less than 0·07 per cent. of carbonic acid (the limit is placed at 0·06 by some authorities), and he found that the air of certain cotton factories in Manchester contains as much as 0·30 per cent., or more than four times his limit.

An Indian spinning room, such as has been referred to, should be supplied with at least 1,800 cubic feet of air per operative per hour. This, for the 80 persons employed, would amount to 2,400 cubic feet of air per minute, and would require a fan with a 4-foot wheel making 108 revolutions per minute. It would require less than one-horse power to drive it. The air should be distributed by two sheet iron pipes running the whole length of the room and suspended overhead. Openings should occur at every 20 feet on the upper side of the pipes with a sliding lid, so that the orifice may be adjusted to give a uniform discharge. No special outlets need be provided in the building for the air.

In this manner each operative will receive his air supply continuously, and regularly, as the spindles receive their yarn, for breathing is a continuous process just as spinning is.

Cotton mills situated on the Coast have nearly always sufficient moisture in the air for the purposes of manufacture. It is only during the rare prevalence of land-winds that any difficulty arises: but in the interior, during the rainless season, the air is nearly always too dry for the purposes of spinning and weaving, and must be moistened by some means, otherwise the production of yarn falls off to the amount of 8 and sometimes 12 per cent.

According to the researches of Dr. Bowman of Halifax, Dr. Schunck of Manchester, and others, the cotton fibre contains two elements that play a very important part in the process of manufacture. Cotton wax is a substance found in all cotton fibres. It fuses at 186·8° Fah., and solidifies at 179·6°. At temperatures below this point it varies in hardness, and as the fibre gets older it begins to oxidise and dry, and is no longer affected in the same manner by heat. It ispartly for the purpose of softening this wax and rendering the fibre more pliable that mills are heated. Old cotton requires a higher temperature to soften it than new cotton.

The existence of moisture in the cotton fibre is, however, the most important condition affecting good spinning. When exposed freely to the air, the weight of loose cotton varies with every change of temperature or of moisture. If a small sample is hung in a delicate spring balance, it becomes a hygroscope indicating changes that take place in the atmosphere during the day. The absorption of water renders the fibre thicker and softer than when dry, so that when twisted together it lies closer together and forms a stronger thread. This is not so much due to an increase of strength of the material forming the thread, as to the fact that every fibre has its fair share of work. They then resist all together. Mr. W. Thomson, F. C. S. of Manchester, found by experiment that bay reducing the amount of moisture in cotton below 8·93 per cent.,the strength of yarn to resist breaking was rapidly diminished, while a considerable increase of moisture above the natural amount was not accompanied by a proportionate increase of strength in the yarn.

It is then evident that moisture has a most important part to play in the spinning of cotton, as it gives greater softness to the yarn, and allows it to twist more freely than when dry. The shorter the staple the more important does this become.

No scheme of ventilating a mill could therefore succeed if it did not provide for moistening the air supply so as to prevent it in the dry weather from desiccating the cotton fibre.

There is no fixed condition of air, as regards temperature and moisture, that is best for all kinds of cotton, but 85° Fah. for temperature and 65 per cent. for moisture may be regarded as approximations to the best condition. These figures may be increased up to 88° or 90° and 87 per cent. without affecting manufacture injuriously, during very hot weather.

By a fortunate coincidence, the best conditions for cotton manufacture are also favourable to the health of the operatives, but the moistening of the air should not be permitted, or attempted, without an adequate provision for the supply of fresh air to carry off the water vapour as soon as it becomes too hot.

Much injury has been done to the operatives by flooding the floor of tightly closed mills in hot weather, and loading the foul, hot air with water vapour. It frequently throws 10 per cent. of the operatives on the sick list.

Various attempts have been made to correct the dryness of the air in Indian mills by means of apparatus designed in England for the home climate, and allowing nothing for the difference in temperature and dryness of the air in India. Nearly all have been abandoned on account of inefficiency both in ventilating and in moistening. The fans used for the purpose have nearly always been *blast fans* running at a high rate of speed, with great waste of power, instead of slow running ventilating fans.

Exhausting fans have been tried in Bombay fixed on the ridge of a roof. Their failure was mainly due to the tendency of the fresh air to go in straight lines from the inlets at doors or windows to the fan.

In order to obtain a satisfactory distribution of air for ventilation, it must be *blown* in and discharged at orifices suitably distributed about the room. This is all the more important, since it is necessary to heat the room artificially at certain seasons and to moisten the air at others. The ventilating and moistening arrangements must form part of the same apparatus, since neither can be safely used without the other. The air alone, in hot, dry weather, would desiccate the cotton, and the water alone would be injurious to the operatives.

There are already before the public a good many appliances known as "humidifiers" for moistening the air in factories. They may be roughly divided into two classes, one in which the water is broken up into mist by escaping at a high velocity from a small orifice either into the air or striking a plate, and the other in which a small stream of air under pressure strikes a small stream of water and disperses it into mist, which is promptly absorbed by the dry air.

In Lacy's humidifier the air passes through one or more perforated trays containing water, at the moment of leaving the propelling fan, and is then distributed in sheet iron pipes suspended overhead. This apparatus, which has acquired considerable popularity in England, does not moisten the air sufficiently for India, unless with an excessive area of water trays.

The Garland apparatus, an American invention, uses compressed air to vaporize the water in a very effective manner, but the air is not sufficient in quantity to ventilate a closed room. It will not, therefore, serve alone.

The heating, ventilating, and moistening pipes should be regarded as parts of the same apparatus for *manufacturing* the climate of the mill. They have all to be suspended overhead, and, when designed at the same time, they should gain both in appearance and in economy of cost. The steam pipes require an accommodation for expansion in length.

A better control of the atmosphere in mills in the interior of India will do more for the prosperity of the cotton industry than all the latest textile machines put together, for, after all that is possible is done in cooling and moistening the air, the Indian spinner will only have succeeded in producing the English conditions in which the machines were designed to work.

The secret of manufacture of the famous Dacca muslins lay principally in working in a moist atmosphere. The spinning and weaving were carried out in underground chambers by day, and above ground at night. In this manner a greater amount of humidity was available in the daytime because of the mean temperature underground giving a higher degree of saturation in the air, and at night the fall of temperature in the air increased the humidity, so the cotton fibre became more amenable to manipulation.

There is still much to be done in reducing the amount of dust discharged from the blow-rooms of cotton factories, not only on account of its injurious properties when inhaled, but also because of the commercial value of all short fibre as paper stuff. Judging from the variety of dust shafts to be seen even in Bombay, no common principle seems to be recognised by the builders. Their diversity is even greater than that of chimney tops. At one mill may be seen a sheet iron shaft about 3 feet in diameter with a hood above it to keep out the rain, the whole festooned with loose cotton; at another the dust tunnel discharges into a large room with a tiled roof into which much of the heavier material falls, but the loose cotton fibre, the most valuable part of the "dust," floats out wherever it gets into an issuing current of air. In a third mill the foot of the blow shaft is a tank of water which only wets the heavy matter that the air current cannot lift, and serves no apparent purpose.

Floating matter in a rising air current will only subside when the current is slower than the rate at which the matter would fall in a still atmosphere.

If this rate of current is impracticable, the matter (in the present instance cotton fibre) may be made heavier by being damped, or it may be arrested by catching against roughened surfaces like coir cordage. It may be advantageous to use both means. During the prevalence of fine rain, or in a heavy fog, all dust and even smoke fall rapidly to the ground. Cotton fibre and other waste material coming from the blowing machines, if treated with a proper supply of water in the form of mist, will be so increased in weight that the heavier part will fall more quickly than at present, and the fibre will be easily arrested by rough cordage in the vertical shaft.

Much of the factory legislation in India is based upon imperfect assumptions due to imperfect premises. The question of ventilation has been neglected while the effect of mill labour on the physique of mill labourer was being studied. The present condition of the mill atmosphere has been accepted as a final one, instead of one demanding an immediate reform which fortunately will be equally beneficial to manufacturer and operative. Sanitary reforms in Indian factories can only be carried out under thoroughly competent inspectors, who can not only point out a defect, but suggest a remedy, and specify, if need be, exactly how the remedy may be accomplished.

When Indian mill-owners, under the pressure of competition or of bad trade, begin to realise the importance of hygiene in its influence upon the cost of production, they will begin to take an interest in the qualifications of their inspectors and to insist on having only thoroughly competent men.

POST SCRIPTUM.

THE reader of the foregoing work cannot fail to note how much has still to be said on the subject of Sanitary Engineering in India, although the volume has already exceeded its proposed limits.

The present condition of sanitary works in India seems to call more for a thorough enquiry into the principles upon which they should be carried out, than for a history of the details of what has been done; the author has, therefore, endeavoured as speedily as possible to bring his observations before the public at a time when several very important sanitary works are in contemplation, while others are undergoing a process of rapid development, which will result in the production of data that should be of great value in the carrying out of other and similar undertakings.

The author hopes in a future Edition to extend many of the subjects that are here treated in a cursory manner, and to give particulars and results of various important works that are, at the present moment, either in the experimental or the progressive stage of development. Among these may be cited the removal of sewage, sewage farming, the economy of water supply, the purification of drinking water, and municipal conservancy. A considerable addition will also be made to the general meteorological data.

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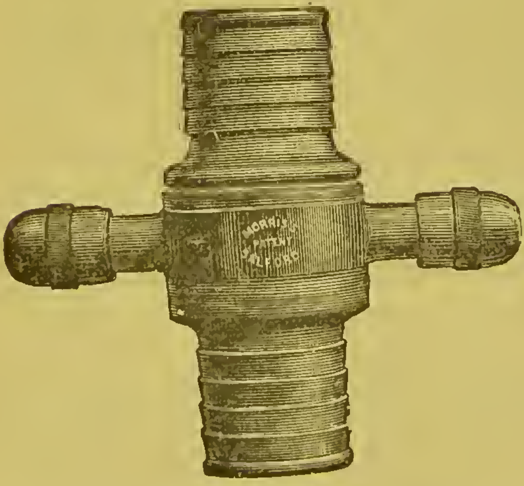

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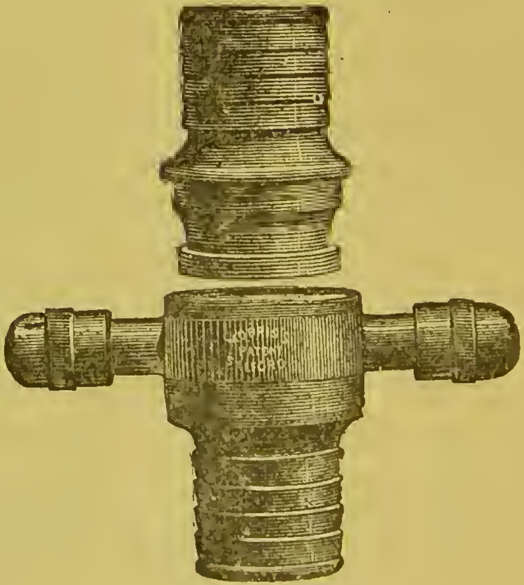

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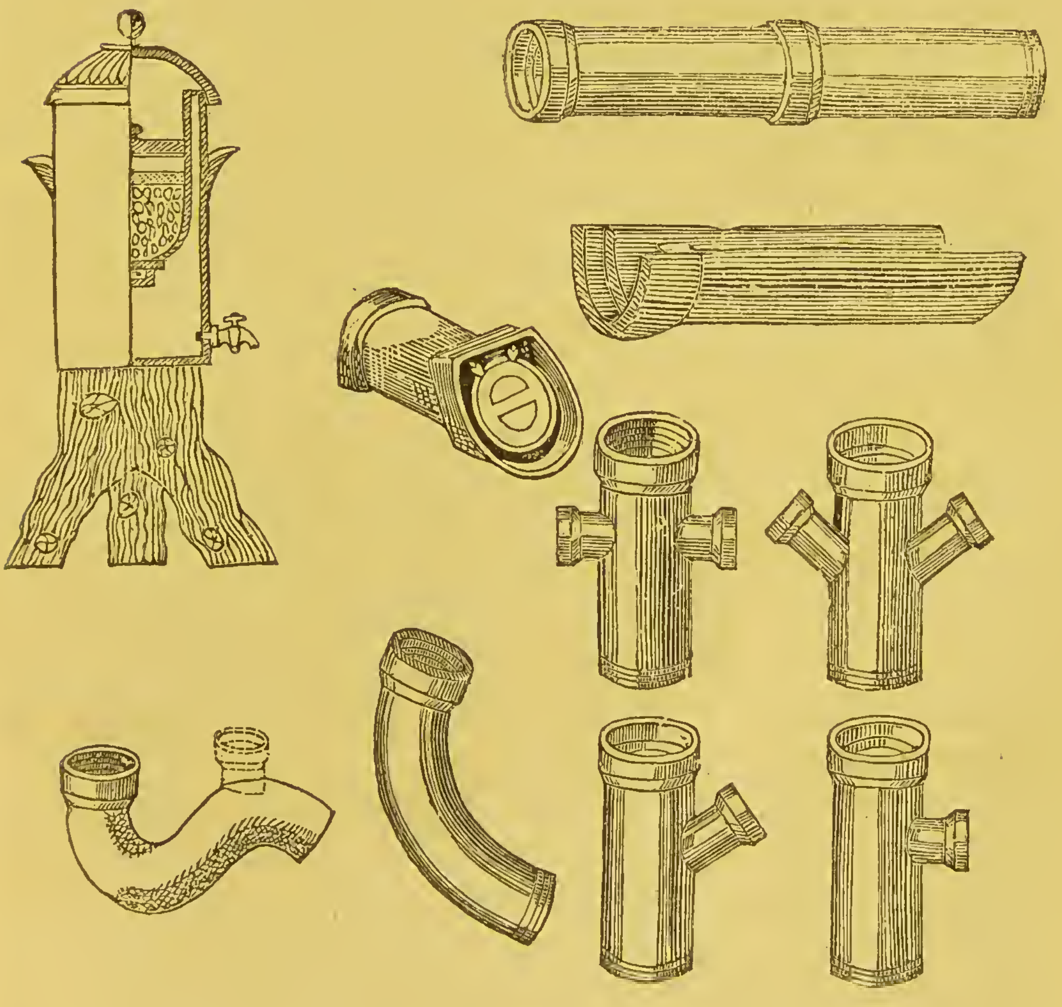

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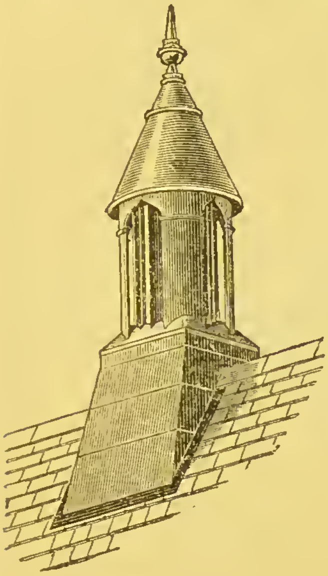

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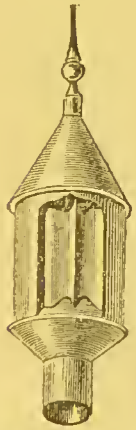

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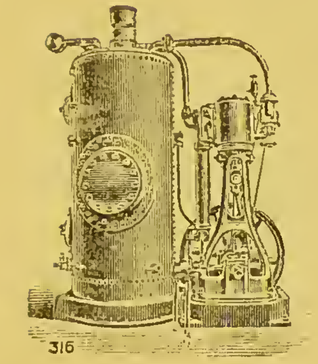

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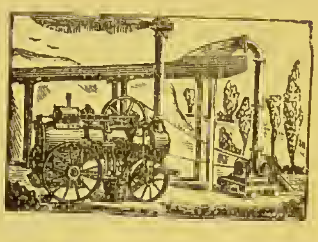

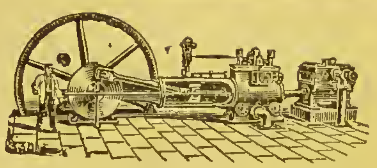

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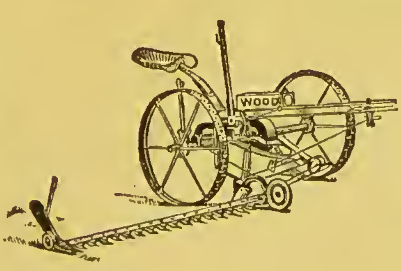

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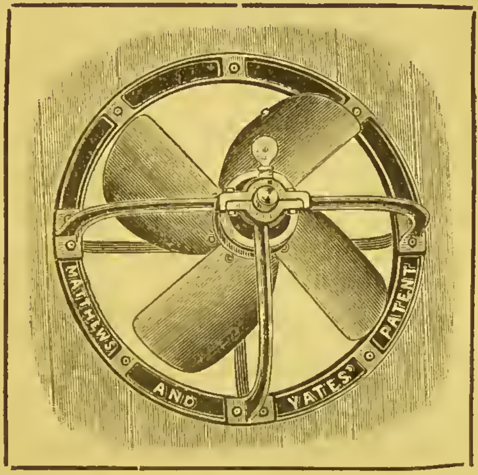

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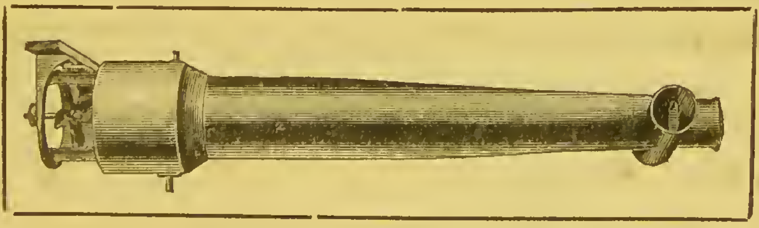

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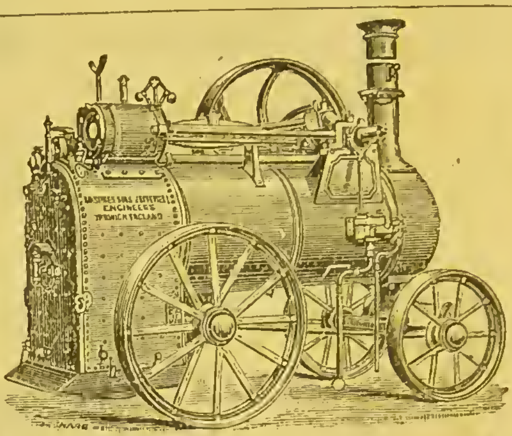

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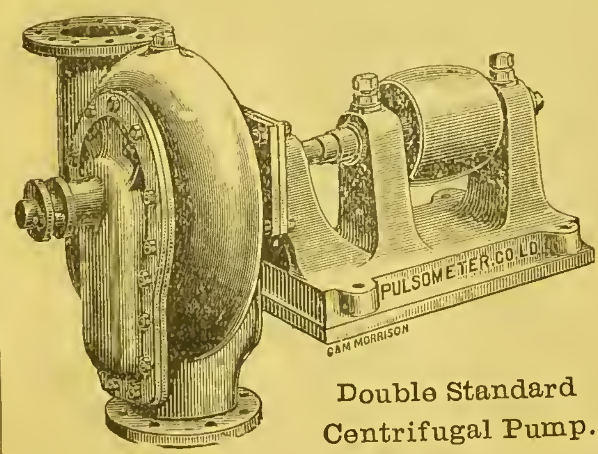

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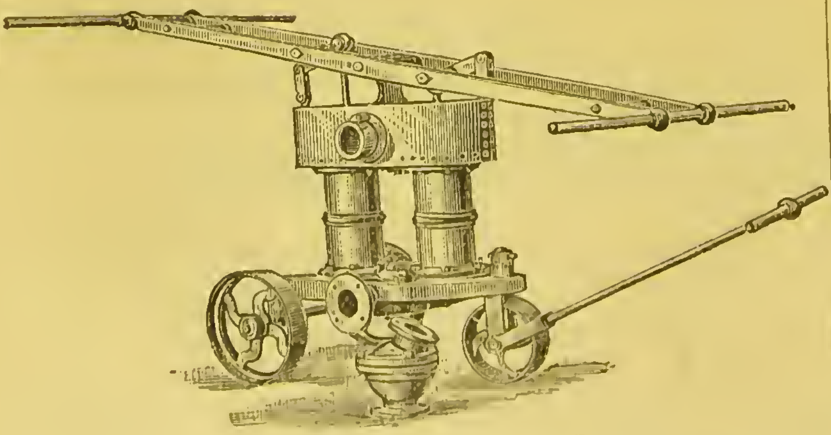

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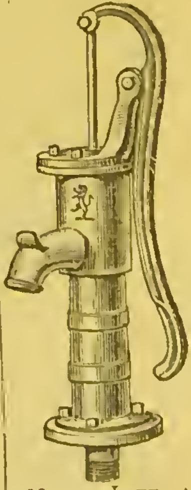

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